Machinery Monitoring Technology Design Methodology for Determining the Information and Sensors Required for Reduced Manning of Ships

by
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Submitted to the Department of Ocean Engineering and the Department of Mechanical Engineering in partial fulfillment of the requirements for the degrees of

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and
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ABSTRACT

A method is developed for determining how to implement sensors and data fusion systems for shipboard use in new or backfit warship designs. The underlying goal of proper implementation of new automation systems is to improve the operational readiness of the ship while simultaneously reducing crew size and operating costs.

The thesis entails defining the method and then using it to determine the information requirements for the efficient implementation of automation technology into ship systems at multiple levels, with a primary focus at the platform level (where the operator interface resides). This includes categorizing the types of information (operational, casualty, combat, logistic, etc) and developing a schema by which each type of information is further defined and presented as an aid to the human operator. Raw sensor data is not the same as information in this context, rather information is the result of processing and analyzing raw sensor data. Information discriminators include refresh rates, frequency and extent of backup/historical logging, levels of data access, levels of automation control, levels of diagnostic and prognostic aids, and types of displays.

A proposed machinery Health Monitoring System (HMS) for Gas Turbine Generators (GTG) for the current and future U.S. Navy Destroyers is examined as a case study to demonstrate the applicability of the implementation method developed in the thesis. Information requirements to support situational awareness for effective and efficient operator performance in a reduced crew environment are identified for the HMS. The required information is based on realistic shipboard scenarios, technical publications and expert interviews relating to the GTGs. Estimates of possible reductions of crew size from implementing the machinery HMS and the resultant costs and benefits of the technology over the life of the ship are analyzed.

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To Christine, Shane and Bryce

Cambridge, Massachusetts, June, 2000

List of Figures

List of Tables

Chapter 1 Thesis Goal and Outline

This chapter states the thesis goal and describes the motivation behind the goal. An outline of the thesis is provided for understanding the scope of the thesis.

1.1 Thesis Goal

The goal is to develop a methodology for determining the sensors and information requirements to properly implement a machinery Health Monitoring System (HMS) aboard ship whose purpose is to provide situational awareness and control of the engineroom machinery, and secondly to demonstrate the Method on the Reduced Ships Crew Through Virtual Presence (RSVP) Machinery Project as a case study.

1.2 Thesis Problem Statement

A design methodology is needed to efficiently design and implement automation technology candidates aboard ship. If the technical capability to accurately and reliably obtain data representing the state of a ship compartment existed today, the ability to present that high fidelity data to a human operator in an informative and meaningful format is lacking. When the crucial elements of time, context, criticality, response action, etc. are considered then the problem of presenting meaningful information becomes more complicated.

1.3 Motivation and Plan for the Thesis

A method needs to be devised to help properly implement new automation technology aboard ship. Too often a design evolves and matures without the benefit of

operator experience and feedback at the deck plate level. To solve the problem of implementation, a clear understanding of what the information requirements are, is essential for the technology to properly be used as an operator aid. The information requirements must be determined in multiple operating contexts and at multiple levels within a system. Operators of various expertise in the organization will use the operator aid for multiple purposes. Consideration of all of these purposes is required in the research on technology implementation. Identification of these multi-variant information requirements forms the basis on which complex systems need to be designed and technology selected.

This thesis entails developing a method for defining the information requirements to efficiently implement automation technology into ship systems. The primary focus of defining the information requirements is at the platform level (where the operator interface resides). Defining the information requirements includes categorizing the types of information (operational, casualty, combat, logistic, etc) and developing a schema by which each type of information is further defined. Discriminators include refresh rates, the frequency and extent of backup or historical logging of data, and determining levels of data access. A method is developed for determining how to implement sensors and data fusion systems for shipboard use into new or backfit warship designs. The method sets automation goals, reviews current practices, develops scenarios and conducts expert interviews. Combining the elements and assigning each requirement to be satisfied by either man or machine automation achieves the functional allocation.

A proposed RSVP machinery HMS for Gas Turbine Generators (GTG) is examined as a case study to show the applicability of the implementation method developed in the thesis. Information requirements to support situational awareness for effective and efficient operator performance in a reduced crew environment are identified for the machinery HMS. The required information is based on realistic shipboard scenarios, technical publications and expert interviews relating to the GTGs. Key components of this effort are reviewing literature from previous research efforts and determining how to apply the lessons learned to the HMS problem as well as developing realistic shipboard

scenarios based on findings to demonstrate (on paper) the information requirement concepts. Based on a review of human engineering papers and references the method was developed and applied to the case study.

1.4 Thesis Outline

Chapter 2 describes the financial and operational implications of applying this technology to reduce shipboard manning.

Chapter 3 is a survey of current automation systems that the candidate RSVP system can leverage from such as the Integrated Condition Assessment System (ICAS) and the USS Yorktown "Smart Ship" initiatives.

Chapter 4 provides a detailed description of the RSVP advanced technology demonstrator (ATD) technology and the machines it is to be used on.

Chapter 5 introduces the proposed method for determining the sensor and information requirements of an automation system to be fielded aboard ship with the background from the previous chapters.

Chapter 6 is a description of the sources used to develop detailed scenarios and task descriptions and presents those scenarios at the end of the Chapter.

Chapter 7 describes the development of a survey and describes the demographics of the interview and survey participants.

Chapter 8 presents the results from combining the survey and interviews with the scenarios and task descriptions to layout the sensors and information required for properly implementing the RSVP machinery HMS.

Chapter 9 discusses the functional allocation of tasks and provides crew reduction

estimates from implementing the technology.

Chapter 10 presents a capital investment analysis of the costs of the RSVP machinery HMS versus the benefits in reduced manning estimated from the previous chapter and the resultant manning and maintenance cost savings.

Chapter 11 presents conclusions from the thesis, such as how well the method worked, suggestions for improving the process and recommendations for further study.

Appendix A describes the site visits used during the research phase and includes many comments on the topic of automation versus manning.

Appendix B is a copy of the questionnaire that was used during interviews and surveys.

Appendix C presents the complete compilation of answers to all of the questions in the survey.

Chapter 2 Why Automate Machinery Spaces for Situational Awareness and Data Integration

This Chapter discusses the motivations and driving forces behind efforts to automate shipboard systems with the goal of reducing manning while maintaining operational performance. In this way the operation and support budgets can be reduced. This information provides a detailed background on why the U.S. Navy and U.S. businesses are pursuing automation technology.

2.1 Motivation for Manpower Reductions through Virtual Presence

As navy personnel costs rise but budget dollars fall, the Navy must seek out systems designed with reduced manpower technology in mind. Current Navy technology development thrusts and ship designs are being driven by pressures to reduce the cost of acquisition and of ownership (life cycle costs). As identified in the 1995 Naval Research Advisory Committee (NRAC) Study on 'Life Cycle Cost Reduction' and reiterated in a 1996 NRAC Summer Study on 'Damage Control and Maintenance for Reduced Manning', a majority of the total cost of ownership is operation and support costs (O&S) [1]. Manpower cost represents 60% of US Navy budget, 30% of DDG-51 direct O&S cost, and 15% of DDG-51 direct Life Cycle Cost (LCC).

As stated in the 1995 NRAC study [1], reducing manning is not straightforward, and "impacts the complex relationship of manpower requirements for operating, maintaining, supporting, fighting and saving the ship. A rational approach to reducing manning requires a systems engineering approach with in-fleet demonstrations of proof of principle." To address this problem, the Navy is pursuing changes in doctrine and the insertion of various technologies aboard selected commissioned ships.

One method for achieving shipboard manpower reduction is to increase the level of

automated controls. Lessons learned from a wide variety of system developments indicate that increasing the level of automation without adequately considering the roles and requirements of humans in the system results in: [2]

- Higher human error rates.
- Greater potential for accidents.
- Extended personnel training pipelines.
- Degraded human and system performance effectiveness.

An engineering challenge to this approach is to integrate human performance with automation and telepresence technology effectively. The Navy needs to design and acquire new ships with integrated, reduced-manning systems acceptable to the fleet. Some of today's technology paradigm roadblocks [3] are notions that:

Automated systems need manual backup. One of the lessons learned from the amphibious assault ship (LHA) experience was that all essential ship systems must have full manual backup capability. In the weapons area, however, the multiple combat situation has become so complex, that manual backup is almost impossible, as well as ineffective. Thus the need for full manual capability is not included in the Aegis system. The perception that the hull, mechanical, and electrical (HM&E) area is different imposes crippling penalties on any attempt to automate those systems [3].

Automated systems need increased maintenance. This is certainly true of complex first generation systems involving manual backup. Second generation HM&E automation systems are predominately computer based and as such make extensive use of common modules, common consoles, and common circuit boards, and common modular software. In fact, maintenance man-hours may be reduced with condition-based maintenance and built-in test procedures, although the skill level of the maintainer will change. There is even a perception that equipment must be manually monitored, even if it is fully automated and coupled to a continuous monitoring system. In the future, the Navy must

overcome this paradigm with highly reliable systems and fleet involvement in requirements and design [3].

Automated systems should be avoided because operator tasks become tedious. If equipment is automated and operators are told to monitor the console, their tasks can become tedious and unsatisfying. To overcome these potential problems, the needs of the human operator have to be considered in the overall design. Embedded training, job design, and human engineering analysis techniques are methods to make jobs less tedious [3].

Digital automation technology is unsuited for a naval environment. Some have argued that ships should not be designed to be totally dependent upon computer systems. The sheer volume of information, plus the availability of distributed computing, will mitigate this paradigm. Similarly, many would argue that computer software cannot be made safe enough for total ship control, yet the aircraft industry is committed to digital automation technology [3].

Fewer people will lead to a reduced damage-control capability. This is one technology paradigm that requires advanced technology, such as intelligent sensors and actuators, to overcome. Having plenty of people on board does provide greatly increased flexibility for damage control and repair. If a ship has a small crew, fewer people will be available to plug holes and put out fires. Some of this loss can be offset by technology , such as closed-circuit television, better smart sensors, and more widespread fire-suppression systems but, ultimately, operators find it difficult to accept a reduced level of active damage control [3].

2.2 Costs and Manning Considerations

Minimum or optimal manning is a core requirement for all surface ship design programs, and has strong impacts on ship design and life cycle cost. Estimates of savings in the new family of surface combatants SC-21 (which has evolved into DD-21), if the

manning reduction goal is achieved, is up to 11 billion dollars over the 30 year lifecycle [4]. Manning reduction also substantially influences ship characteristics and design. The reduction of onboard personnel will significantly reduce habitability and human support systems space requirements, allowing for larger payloads, or smaller ships. Reduced manning also places fewer people in harm's way during a conflict.

With respect to manning, US surface combatants policies are different than other navies as can be seen in Figure 1 [5]

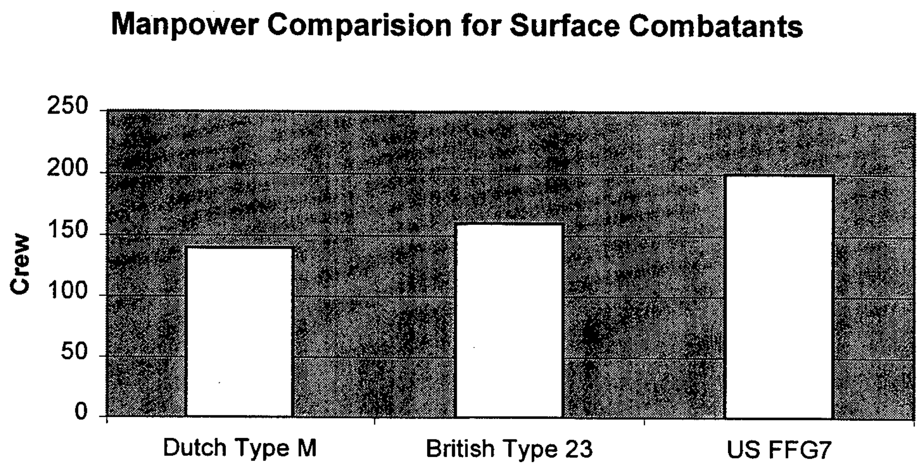


Figure 1 Manning for Frigates (3500-4000 tons)

The underlying motivation in manning reduction is cost, but there are several other important motivations to reduce crews, including the number of crew lives at risk, reduced reaction and response times, and shipboard job enrichment. The most important technologies that allow for the concept of an automated ship are:

Digital Computers	Fiber Optics
CD-ROMs/Software	Global Positioning System
Graphical User Interface	Electronic Charting and Navigation
Large Flat Screen Displays	Corrosion and Wear Resistant Coatings
Expert Systems	Robotics
Reliable Sensors	

Warship personnel work with a multidimensional workload resulting from functional requirements and tasks, maintenance requirements, training requirements and

safety concerns. Figure 2 [3], shows the Total Workload Distribution for DDG51. This chart illustrates the many tasks a ship's crew has to execute.

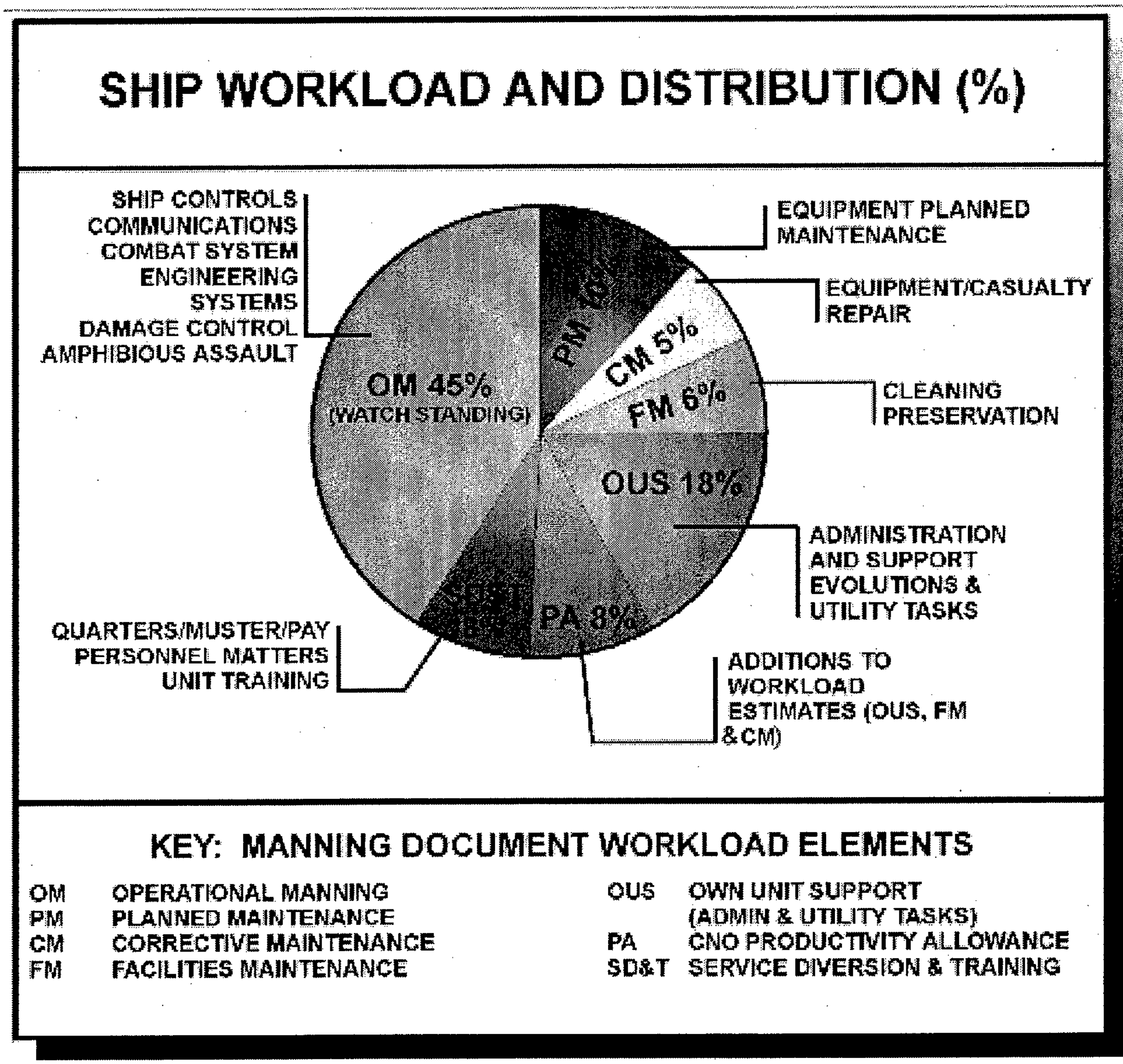


Figure 2 Total Workload Distribution for DDG51

This workload is variable, with manning driven by the highest workload periods such as General Quarters and Damage Control. Manning reduction cannot be resolved with technology alone, since it is a multidimensional problem involving human resources that requires major changes in doctrine, tradition, culture, training and procedure.

2.3 Automation Considerations

Warship automation

An autonomic ship can be described as a ship where the people decide *what* to do and the ship *makes it happen* [6]. To achieve this objective, it is necessary to do a complete redesign of the surface combatants, or more accurately a complete rethinking of the design process. Such a ship will require some type of intelligent operator aid. For example it may be designed based in a Rational Behavior scheme that has been used for control of experimental Autonomous Underwater Vehicles (AUV's) [7]. This approach considers three intelligence levels: strategic, tactical and execution levels. The strategic level involves all decisions involved with the specific mission objectives. The tactical level is the link between the former and the execution level consists of preplanned actions based on the system state. The execution level is responsible for controlling the actual machinery, sensors, weapons, etc. For the case of ship automation, the crew will make the strategic level decisions, while the ship will automatically execute all tactical and execution level tasks. A highly automated and minimally manned ship should consider meeting the following general requirements during the design process [6,7]:

Automated ship motions control and navigation (tactical).

Automated Command and Control (tactical level-strategic with veto*).

Combat Systems (tactical-strategic with veto).

Engineering and Damage Control (strategic with veto).

Design for redundancy, reliability and survivability.

Highly trained crew for flexible cross-utilization.

Extensive off-ship support.

*veto refers to the ability for the human to intervene or override an action.

2.4 Automating the Monitoring and Control of Machinery

The goal of a machinery HMS is to give situational awareness of the machinery

condition and provide assistance to the operator in monitoring the machinery, diagnosing problems, taking proper corrective action and archiving sensor readings for trend analysis. Automated machinery monitoring and health assessment will enable rapid determination of system configuration and operational status, early detection of system faults and adverse operating conditions, timely and efficient equipment restoration decisions, and logistic support coordination (scheduling repairs and ordering spare parts).

Roving engineroom watchstanders will no longer be required. The total potential savings include the direct manpower savings from reduced paperwork, watch standing and maintenance tasks resulting in shipboard crew reductions, and the indirect manpower savings from reductions in the shore based infrastructure required to support larger crews and larger maintenance loads.

A secondary benefit of a machinery HMS is the continuous knowledge of the condition of the machinery. The current preventive maintenance system requires components to be replaced periodically without regard for actual condition. If the approach to maintenance is changed from the current periodic work schedule to a condition based maintenance (CBM) schedule then automated machinery monitoring will reduce the maintenance workload and repair parts used, by replacing components only when they begin to exhibit signs of wear. Additional savings will be realized because maintenance can often result in lost operating time due to improperly performed maintenance, which can cause material and labor cost overruns.

2.5 Performance Gap

Current sensing technologies and systems use discrete sensing capabilities, and hard-wired architecture for system communication and power. The need to support total ship situational awareness for reduced manning concepts requires a significant increase in the number of sensors. The desirable attributes of affordability and reliability drive the design to be a low power, wireless sensor system, most likely utilizing commercial off

the shelf (COTS) technology [9].

The amount of processing capability and bandwidth, and wireless communications impacts system power requirements. The result is a power requirement gap between current and future sensing systems. The new systems would require unrealistic amounts of power unless low power components are developed and refined. The ability to transform sensor data into situational awareness requires an increase in complexity of data processing beyond current shipboard applications. A performance gap exists in the integrated processes and methods used to coalesce multi-variant data into useful coherent information to support a reduced manning environment. The information is used as input to "smart operator aids" to support decisions at the ship level [9].

In summary, automation to reduce manning has many economic, political, and social implications, and this chapter provided information to help understand the issues. The next chapter presents a survey of current automation technology initiatives that are underway in support of automation to reduce manning.

Chapter 3 Overview of Current Automation Systems

This chapter summarizes RSVP related automation technologies that are currently under development for eventual military use, or have already been fielded in military roles. This chapter is an overview of current automation systems. The systems discussed are the Integrated Condition Assessment System, the smart ship initiatives, the condition based maintenance initiatives, personnel status monitors, the commercial technology insertion program, micro electromechanical systems (MEMS) technology development, fire detection technology, damage control automation for reduced manning, built-in calibration for sensors, battery less sensor development, and pre-hit reconfiguration management technology.

3.1 Integrated Condition Assessment System

The Integrated Condition Assessment System (ICAS) [10] is comprised of COTS software and hardware products communicating via a local area network (LAN) for the purpose of monitoring and analyzing machinery performance on board US Navy ships. Such an analysis is a useful and necessary tool for enabling condition-based maintenance in the fleet. ICAS hardware includes the following COTS products: workstations, sensors, portable data terminals, portable data analyzers (for vibration data), and data acquisition units. ICAS software includes the ICAS shell top, which incorporates the graphical user interface; the ICAS configuration data set (CDS) which contains the engineering knowledge base for the equipment being monitored; Windows NT operating system; and electronic logistics links.

Machinery data enters ICAS in one of three ways. Data buses can collect data when interfacing with existing machinery. On line sensors can continuously feed the system with data. Also, the data can be collected manually via the portable data terminal or portable data analyzer and uploaded into the system.

The ICAS software utilizes this data in several ways. Data is periodically sampled for each piece of equipment and entered into the trend database. This data can be viewed on a coordinate axis as a trend for any monitored parameter versus any other monitored parameter. Predefined machinery performance curves can be overlay on the trend data for certain relationships allowing the viewer to compare the trend data to the performance curve. Data is also fed into an expert system, which looks for combinations of inputs that indicate certain faults that have been identified in the CDS as conditions that warrant maintenance actions. The user is then prompted by the software to follow a procedure of troubleshooting or maintenance actions. If a recommended action is described in any of the existing on line logistic data links, an icon will appear allowing the user to view the specific procedure by simply pointing and clicking. Logistic links are available for Planned Maintenance System (PMS), EOSS, and Integrated Electronic Technical Manuals (IETM)s.

In addition to using ICAS for troubleshooting, it can also be used for failure analysis. One of the most effective ways to do this with ICAS is by defining "events". Events are a set of conditions which, when encountered, will trigger ICAS to write machinery data to disk for a predetermined amount of time before and after the event occurred. This data can then be viewed in light of the failure and used in the failure analysis. Log data can be taken with ICAS portable data terminals (PDT)s rather than using paper logs. This has two positive effects. First, the ship's engineering logs will not be taken on paper, so a savings in paper and storage for the paper logs is incurred. Secondly, the log data can now be incorporated into the various ICAS analysis and trend databases for future use. The next generation system should automatically log data, perform trend analysis, record events, predict failures, and recommend action.

ICAS conforms to many open architecture standards including MIMOSA, OLE, ODBC, NET UDP, NET TCP/IP, and OPC. The intention of the ICAS program is to maintain as open a system as practical so that ICAS can be used as a launching pad for incorporating other COTS software technologies into the shipboard maintenance and monitoring system. ICAS can transfer data into and out of the system via a local area

network (ATM, TCP/IP, Ethernet, or peer to peer) or a serial data stream. ICAS can presently interface with the machinery control data buses on board the following class ships: CG-47, DDG-51, MCM-1, MHC-51, and DD-963.

Table 1 Ships with ICAS as of December 1999

DD-963	**DDG-51**	**CG-47**
USS SPRUANCE (DD-963)	**USS THE SULLIVANS (DDG-68)**	USS YORKTOWN (CG-48)
USS RADFORD (DD-968)	**USS MILIUS (DDG-69)**	USS GATES (CG-51)
USS PETERSON (DD-969)	**USS HOPPER (DDG-70)**	USS LEYTE GULF (CG-55)
USS CARON (DD-970)	**USS ROSS (DDG-71)**	USS SAN JACINTO (CG-56)
USS BRISCOE (DD-977)	**USS MAHAN (DDG-72)**	USS MONTEREY (CG-61)
USS STUMP (DD-978)	**USS DECATUR (DDG-73)**	USS GETTYSBURG (CG-64)
USS MOOSEBRUGGER (DD-980)	**USS MCFAUL (DDG-74)**	USS HUE CITY (CG-66)
USS HANCOCK (DD-981)	**USS DONALD COOK (DDG-75)**	USS SHILOH (CG-67)
USS NICHOLSON (DD-982)	**USS HIGGINS (DDG-76)**	USS ANZIO (CG-68)
USS O'BANNON (DD-987)	**USS PORTER (DDG-78)**	USS CAPE ST GEORGE (CG-71)
USS DEYO (DD-989)		
USS HAYLER (DD-997)	**MCM-1**	**MHC-51**
	USS DEVASTATOR (MCM-6)	USS OSPREY (MHC-51)
FFG-7	USS SCOUT (MCM-8)	USS HERON (MHC-52)
USS CLARK (FFG-11)	USS PIONEER (MCM-9)	USS PELICAN (MHC-53)
USS MORISON (FFG-13)	USS GLADIATOR (MCM-11)	USS ROBIN (MHC-54)
USS GROVES (FFG-29)	USS ARDENT (MCM-12)	USS ORIOLE (MHC-55)
USS DOYLE (FFG-39)	USS DEXTEROUS (MCM-13)	USS KINGFISHER (MHC-56)
USS HALYBURTON (FFG-40)		USS CORMORANT (MHC-57)
USS TAYLOR (FFG-50)		USS BLACK HAWK (MHC-58)
USS KAUFFMAN (FFG-59)	**CV/CVN**	USS FALCON (MHC-59)
MCS-12	USS KITTY HAWK (CV-63)	USS CARDINAL MHC-60)
USS INCHON (MCS-12)	USS CONSTELLATION (CV-64)	USS RAVEN (MHC-61)
		USS SHRIKE (MHC-62)
	LSD-47	
LHD-1	USS COMSTOCK (LSD-45)	
USS WASP (LHD-47)	USS RUSHMORE (LSD-47)	

ICAS Benefits

ICAS benefits are realized in several areas. First, there is a reduction in time directed PMS as a result of the use of the ICAS system. This is a direct result of the move from time based maintenance to CBM. An additional benefit of this move is that the maintenance dollars available for a ship are more effectively spent. ICAS creates a reduction in troubleshooting time due to the availability of data to the troubleshooter, and the expert system which uses acquired data to analyze faults and provides a procedure to the user

complete with logistical links. The time required to generate work requests is reduced with ICAS since it incorporates a 2K (maintenance request form) generator. There has been a measured reduction in casualty reports (CASREPS) between ships with ICAS and ships without ICAS. This can be attributed to more effective maintenance, fewer failures induced by open and inspects, and more advanced warning of an impending failure.

In summary, ICAS is a CBM enabling tool which monitors machinery data and analyzes the data to assess equipment condition. ICAS utilizes trending, expert analysis, and alarms to provide the user with a picture of machinery performance while enabling time and cost saving practices such as paperless logs. ICAS is continually being made more open to allow for interfaces with other systems and products [10].

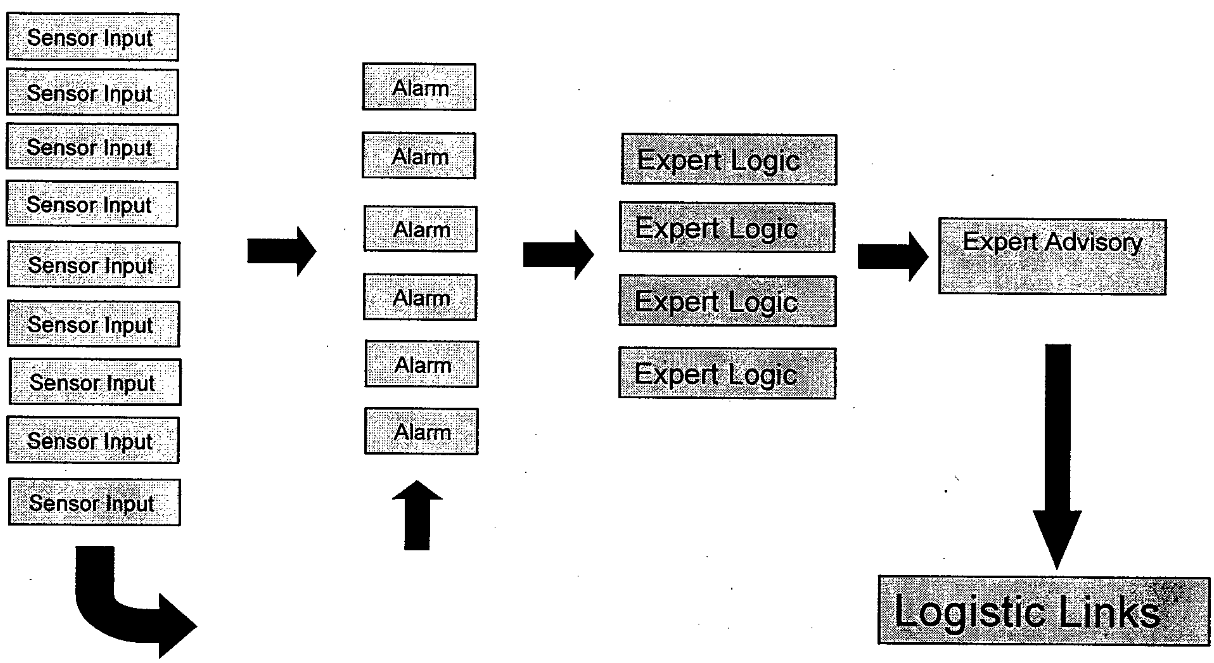


Figure 3 ICAS Machinery Monitoring System Structure.

Navy Policy Toward ICAS

Logsheet Automation is the initial emphasis and objective, independent of all others, because it saves the most man-hours and improves the efficiency of processes.

The Configuration Data Set (CDS) is focused on equipment failure modes derived from Reliability Centered Maintenance (RCM) discussions with interested engineering administrations such as the ISEA, OEM, FTSC, fleet, and SYSCOM.

The Commander of Naval Surface Forces U.S. Atlantic fleet (SURFLANT) policy requires ships to go paperless within 45 days of implementation of ICAS version 4.0. Although the data is primarily shipboard resident, SURFLANT ICAS policy dictates that data be downloaded to cartridges and sent to local FTSC via regular mail.

List Of Components With ICAS Installations

LM 2500 (GTM)

501-K17(GTG)

HPAC

LPAC

Line Shaft Bearings

Main Reduction Gear

Heat Stress

Air Conditioning Plants

Refrigeration Plants

Controllable Rate Propeller

Dehydrators

Distillation Plants

Reverse Osmosis (1st and 2nd Pass)

Vapor Compression Distilling Pant

Electric Plant

Sounding and Security

Vibration on various equipment

Various Auxiliaries

Summary Alarms/Indications

Ancillary Main Propulsion

Lube Oil and Fuel Oil

ICAS Savings Sources

In logsheet administration the time spent recording readings and reviewing logs is non-productive and repetitive and must be eliminated. Reducing unnecessary PMS and unscheduled Maintenance Actions reduces the total man-hours spent on maintenance

Diagnostics and Prognostics provide Indications that equipment is not performing to specifications and provides maintenance recommendations and guidance.

Automating 45% of DDG-51 Logs saves approximately 15,000 man-hours annually with current automated logsheet savings of $303K/hull/yr. Future savings on

DDG-89 and follow on ships with a fully sensorized engineering plant are expected to be $691K/hull/yr.

Efforts are currently underway to document savings in the following areas; PMS reductions, vibration analysis, potable water interface and fuel flow interface.

The strategy is to continue diagnostic and sensing capabilities for systems that are high in critical CASREPS, manpower intensive for PMS, log recording and reviewing intensive, high in depot level maintenance expenditures, or high in total ownership cost expenditures [10].

3.2 USS Yorktown (CG-47) "Smart Ship" Initiatives

The smart ship measures started following a brief from the NRAC panel on reduced manning to the Chief of Naval Operations (CNO) [11]. The report concludes that the major obstacles to reduced manning and the resultant lower lifecycle costs for today's ships are culture and tradition and not the lack of proven technology. The challenge is to demonstrate that a reduction in workload and manpower on operational ships is possible while still maintaining mission readiness and safety. SURFLANT chose the U.S.S. Yorktown (CG-47) for the project in which the smart ship initiatives would be implemented to demonstrate the concept.

The smart ship project has demonstrated that reduced manning is possible while maintaining mission readiness and safety with a net positive return on the investment. Large potential savings in manpower operation and maintenance costs aboard ship offset the costs for technology implementation and procedural changes. Some issues still remain prior to removing crewmembers, but the workload requirements and the necessary technology are not obstacles in reaching smaller crew goals.

Reduced manning is achieved by changes in three basic areas. They are policy and procedure, technology, and maintenance methods. While stations and workload assignments are based on a philosophy of a flexible workforce with a routine daily workforce in a watch team focusing on outstanding responsibilities. Manpower is flexed

to perform emergent activities and then relaxes back to the core team as the situation allows.

The navigation, machinery control, equipment condition monitoring, and information management aboard ship have been automated using selected core technologies. The seven core technologies used are the Engineering Control & Surveillance Equipment (ECSE), the Damage Control System, the Fuel Control System, the ICAS, the Integrated Bridge System, the Shipwide Area Network, and the Wireless Internal Communications System. These functions are performed and supported by Comercial Off the Shelf (COTS) computers, linked by a fiber-optic LAN.

Maintenance methodology has been shifted to reliability centered maintenance (RCM) versus the standard PMS system. The RCM approach has reduced scheduled maintenance workload by 15 percent, with no degradation of equipment readiness

The U.S.S. Yorktown was evaluated following implementation of all policy, procedure, technology, and maintenance initiatives and found to have reduced total workload by 30 percent. The potential crew reduction would be 44 enlisted men and 4 officers. Savings of $2.87 million are possible from direct manpower reductions, and indirect manpower reductions, from reduced shore infrastructure, and savings of O&S costs. Technology installations evaluated as a single package return the investment in 17 years. Technology enables the policy and procedure changes, and when combined with the RCM maintenance philosophy the payoff is two years.

To compare whether the smart ship crew reduction was sustainable the material deficiencies and repair parts used were compared with the ship operations prior to the smart ship initiatives and found no significant change, indicating the same level of readiness after crew reduction. The survey of crewmembers aboard smart ship showed favorable opinions of the initiatives across all ranks. An analysis of labor man-hours available using the flex team concept showed that the same number of hours is available.

The main concern of evaluators was maintainability and logistics support for the new technology and software. Their concerns were due mainly to the rapid prototyping processes used to buy the smart ship initiatives technology, and can be or are being resolved. The upgrade was estimated to take 10 weeks but extended to almost 40 weeks, however this is still very rapid when compared to previous standards that took up to 5 years from the idea being accepted to entering the fleet.

The conclusion of SURFLANT is that the Yorktown demonstration with 50 less enlisted men and 4 less officers has not shown any reduction in readiness or performance. The smart ship project is a success, providing a significant return on investment from a modest technology cost. Future plans are to evaluate smart ship initiatives in destroyer squadrons and to seek funding for proven technology backfits and continue to find more workload saving ideas [11].

3.3 Condition Based Maintenance Advanced Concepts Initiative Program

The ONR sponsored Condition Based Maintenance Advanced Concepts Initiative (CBM ACI) [9] set out to develop an open architecture to implement advanced hardware and software diagnostic tools in support of equipment health assessment. The goal is that the architecture be cost effective and enable monitoring at the component, system, and platform levels. ACI efforts include advanced sensor development, wireless reconfigurable networks, and diagnostic and prognostic algorithms in the software. The focus of the ACI Machinery Diagnostics thrust is to examine applicability to the 501-K34 Ship Service Gas Turbine Generator (SSGTG) and the York 400 ton Air Conditioning Plant. The multi-level machinery health assessment will provide machinery monitoring and predictions of component s remaining time until a problem may occur. This situational awareness of the systems will enable reductions of crew workload associated with maintenance and operations, by allowing "just-in-time maintenance and eliminate

the need for roving watchstanders taking hand written readings of the machinery status.

3.4 Personnel Status Monitor

The Personnel Status Monitor (PSM) [9] is being developed under DARPA's Defense Healthcare Technologies Program at SARCOS. The PSM combines medical system protocols and state-of-the-art miniature physiologic sensors, geo-locators, microprocessors, and RF communications in a system worn by the user. The user's presence, vital signs, and medical condition can be monitored from a remote location. RSVP will leverage this system to provide personnel monitoring in ship compartments.

3.5 Commercial Technology Insertion Program

The Indian Head Division of the Naval Surface Warfare Center (NSWC) is involved in the evaluation and testing of commercial MEMS sensors for Navy use with their Commercial Technology Insertion Program (CTIP) [9]. OSD/ONR, DARPA, and the Naval Surface Fire Support (NSFS) office sponsor CTIP. The opportunity exists for selected RSVP sensors to be tested as part of the ongoing CTIP effort, as well as leveraging ongoing testing of other MEMS sensors.

3.6 MEMS Technology Development

DARPA views MEMS as a revolutionary enabling technology that merges onboard communication capability and external communications with sensing and actuation to change the way people and machines interact with the physical world.

The MEMS programs [9] being funded by DARPA have three major thrusts: advanced device and process concepts; systems development and insertion, and support access technologies. The three thrusts cut across a number of projects and focus on application areas including; inertial measurement; fluid sensing and control; electromagnetic and optical beam steering; distributed networks of sensors and actuators; mass data storage; active structural control; analytical instruments; integrated chemical

processing; signal processing; and precision assembly. RSVP will review and leverage relevant technology advances being developed through DARPA's efforts.

3.7 Fire Detection Technology

The Fire and Safety Threat classifier (FAST) Program [9] demonstrated the ability to detect, localize and classify various types of small shipboard fires using multiple types and numbers of fire sensors. The National Institute of Standards and Technology (NIST) sponsored, performed and documented research into fire detection sensor requirements and summarized these in a FY97 "Advanced Fire Detection System Evaluation" report. These efforts will be reviewed prior to the selection and evaluation of fire detection sensor hardware and software.

3.8 Damage Control Automation for Reduced Manning Concept

The purpose of the Damage Control Automation for Reduced Manning Concept (DC-ARM) [9] is to improve the capability of reliable automated sensing, decision-making, control and actuation technologies to effect up to an 85% reduction in damage control manning for future combatants. This automated system must combine both fire protection and fluid control. The fire protection will be through an automated system for the investigation, containment and suppression of the fire, and an automated smoke and heat management system. The fluid control will be again through an automated system for the investigation and containment of the flooding, and the automated reconfiguration of the different fluid systems. This concept will result in a reduction in the life-cycle cost resulting from reduced equipment damage losses, it will improve the performance by increasing the survivability through a 75% reduction in casualty response time and by improving personnel safety through reduced exposure to the hazardous environments. Finally, it will increase the ship design flexibility by having an open architecture to affordably accommodate future generation technologies.

3.9 Study Of Built-In Calibration For MEMS Sensors

An FY97 effort conducted by the Navy's Metrology R&D Program through the Naval Warfare Assessment Division (NWAD), and the Naval Research Laboratory (NRL) will identify current and future shipboard sensor measurement and calibration requirements. The technical objective of this task is to survey the current MEMS based sensor technology base and assess which sensors are compatible with the concept of built-in calibration (BIC) [9] and with the requirements will be compiled and utilized in the RSVP architecture concept. The Logistics Engineering Advanced Demonstration (LEAD) proposal supports the Navy's proposed introduction of MEMS sensors through the RSVP Program and will be transitioned through the DD-21, CVX, NSSN and other ship programs.

3.10 Batteryless Sensor Development

Several efforts related to batteryless sensors [9] will be reviewed for application to the RSVP approach. An FY95 small business investment and research (SBIR) program "Batteryless Sensor for Intrusion Detection" developed a self-powering, wireless mechanical motion sensor. The development of a self-powering, batteryless, power sources for MEMS sensors is occurring in the "Intelligent Power For Microsystems" program at Oak Ridge National Laboratory (ORNL). Research into embedding wireless, batteryless, sensors into structural composites is being sponsored by the Naval Research Laboratory (NRL).

3.11 Pre-Hit Reconfiguration Management

This program is sponsored by NAVSEA 03R, and investigates the application of an advanced networked computing infrastructure aboard navy ships which ties into both combat systems and damage control systems. It would have the ability to detect, assess and predict the impact location and damage of an incoming threat, and using advanced reasoning and control algorithms, reconfigure ships systems before impact to minimize

damage and increase survivability. The program is targeted for DD-21. RSVP could potentially provide at the compartment level, sensor data/information and network capabilities to support this effort [9].

The Reduced Ships crew Through Virtual Presence technology is not mentioned in this Chapter. It is described in detail in Chapter 4 because it is the technology used for the case study to test the methodology developed in the thesis. The initiatives were described because they are the basis from which many elements of the RSVP system as a whole have been developed.

Chapter 4 RSVP Technology

This chapter describes in detail the RSVP technology applications and implementation time line. The machinery and control consoles that will use this technology are also described in detail. This information provides the context to understand how the methodology for determining what sensors and information is required to field an automation system properly aboard ship, will be applied.

4.1 BACKGROUND

Presently the ability to present high fidelity data to a human operator in an informative and meaningful format is too limited for the automation and manning goals of the 21st Century Navy. To move closer to the goals, a clear understanding of information requirements for assisting various machinery operators in multiple contexts and levels within a system is required. Identification of these multi-variant information requirements forms the basis on which the complex monitoring and control systems need to be designed and technology selected. Technology insertion will include advanced sensors, wireless networking, distributed monitoring, processing, and advanced reasoning capabilities. Current systems such as the Damage Control System (DCS), automated Machinery Control System (MCS) and the Integrated Condition Assessment System (ICAS) provide some of this capability. However, the full level of automated monitoring and situational awareness and assessment required to safely reduce manning does not exist in these systems today. Reliable, accurate and timely automated ship system assessment and awareness is required to support ship operation in a reduced crew environment.

The RSVP machinery effort will focus on developing and demonstrating a health monitoring capability for an Allison 501K-17 Ship Service Gas Turbine Generator (SSGTG) and an interface capability with a prototype diagnostic system for a York 200 Ton A/C Plant. The basis of this effort is the ONR CBM development efforts by Penn

State ARL on the Allison 501K-34 SSGTG and the development efforts of Honeywell Technology Center, Inc., on a York 363 and 400 ton A/C Plant. Each organization is independently developing a health monitoring capability, an implementation approach, and limited prototype brassboard hardware. Additionally, a virtual presence capability will be defined and an implementation approach developed. How information obtained through the technologies and system(s) demonstrated in RSVP leads to crew reductions will form the basis of the virtual presence capability. An example of this virtual presence approach will be developed for the SSGTG.

The goal of the RSVP system is to give situational awareness of the machinery condition and provide assistance to the operator in monitoring the machinery, diagnosing problems, taking proper corrective action and archiving sensor readings for trend analysis.

4.2 Defining Situational Awareness

A very standard definition of the term situational awareness (SA) is: "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status in the near future." SA is a property of the operator, supported by the information sources available, and not a property of the machine or the displays themselves. The human interface supports the development of SA but is not a part of it. SA is broken into two parts, defining a "situation" and defining "awareness". The definition of a situation is [8]: "a set of environmental conditions and system states with which the participant is interacting that can be characterized uniquely by a set of information, knowledge and response options."

Information is distinguished from knowledge. Information is raw data that is coming in from the environment and is changing frequently. Knowledge is the thoughts and decisions that are in the mind of the operator that he or she uses to interpret the information that is being received. It is based on training and experience. Note that SA is not defined to be the sum total of everything one

might possibly need to know, because SA is situation specific. When asking whether an operator had adequate SA, designers need to know what was needed at the time in question. This is important because the information required is constantly changing and it is impossible to know everything all the time. Thus the elements of awareness, given the situation information and knowledge needed to support anticipated "near" future contexts are:

- Current state of the system (including all the relevant variables).
- Predicted state in the "near" future.
- Information and knowledge required in support of the crew's current activities.
- Activity Phase
- Prioritized list of current goal(s)
- Currently active goal, sub goal, or task
- Time

The information sources can be of great variety, including:

- Sensory information from the environment
- Visual and auditory displays
- Decision aids and decision support systems
- Extra- and intra-crew communication
- Crew member background knowledge and experience

Dr. Pew's definition is [8]: "Situational awareness of a crew responsible for the monitoring and control of machinery encompasses the information and knowledge needed to remotely manage the operations of a machine at each point in time and to anticipate required actions in the near future. This information includes machine

configuration, operating status, and health status together with the status and shared knowledge of supporting personnel. Fusing control requirements with integrated sensor measurements that determine the operational state and condition of a machine supports situational assessment. A key component supporting effective situational awareness is the human-computer interface where the information that is derived from the raw data needs to be presented in a coherent and easily navigable fashion to the operator."

4.3 Description

The RSVP ATD is a three year program beginning in FY00 and culminating in several demonstrations in FY01 including an at sea demonstration on an active Navy ship. The purpose of the ATD is to demonstrate state-of-the-art, developmental and advanced technologies to address multiple monitoring requirements and demonstrate timely, accurate, and reliable monitoring and assessment of the ships state at the compartment level. The RSVP system will provide ship's personnel with information versus data, by using low power electronics, MEMS, wireless networks, distributed processing, and advanced data analysis techniques. Near real time actionable information concerning the compartment environment, machinery health, structural integrity, and personnel status will be presented to an operator in an intuitive graphical format. Compartment level status information will be supported by an explanation capability including corroborating data and the ability to access sensor data.

The objectives of the RSVP ATD are to:

- Define and develop an approach, architecture and system that is reliable, supportable, cost effective, and addresses multiple monitoring requirements for environmental, machinery, structural and personnel.

- Fabricate and prototype hardware, develop software code and integrate into a system capable of providing situational awareness.

- Demonstrate on a deployed ship, the capability to provide reliable, accurate timely and useful information about ship's systems and compartments that will support reduced manning operation.

Implementation of the technologies and approach demonstrated in the RSVP ATD will significantly reduce manual investigation of problems, improve ship condition assessment time and accuracy, and improve operational readiness and availability.

Fully implemented, the demonstrated RSVP system and approach will enable continuous monitoring and assessment of ship compartments and systems. Environmental, structural, and personnel monitoring will reduce detection, classification and response time during a damage control evolution. Machinery monitoring and health assessment will enable rapid determination of system configuration and operational status; early detection of system faults and adverse operating conditions; and timely and efficient asset management and logistic support coordination.

Combined, the ability to rapidly obtain accurate and reliable information about the ship, ship systems and ship's personnel will improve operational readiness and availability, and ability to support mission objectives.

4.4 Component Descriptions

AG9130 Generator

Three SSGTGs [12] supply electric power for the DDG51 Class Destroyer. Two SSGTGs supply all the power necessary under full electrical load conditions. The third unit can be placed in standby and can be placed into operation if either on-line unit fails. Figure 5 shows the side view of the SSGTG. Each AG9130 SSGTG is a module that includes a gas turbine engine, a reduction gearbox assembly, a generator, an excitation control panel assembly (EXCOP), and a local control panel (LOCOP). All are mounted on a common base with the associated engine controls and monitoring equipment. The SSGTG is normally operated and monitored from the Electric Plant Control Console (EPCC) in the enclosed operating space with the Engineering Officer of the Watch (EOOW).

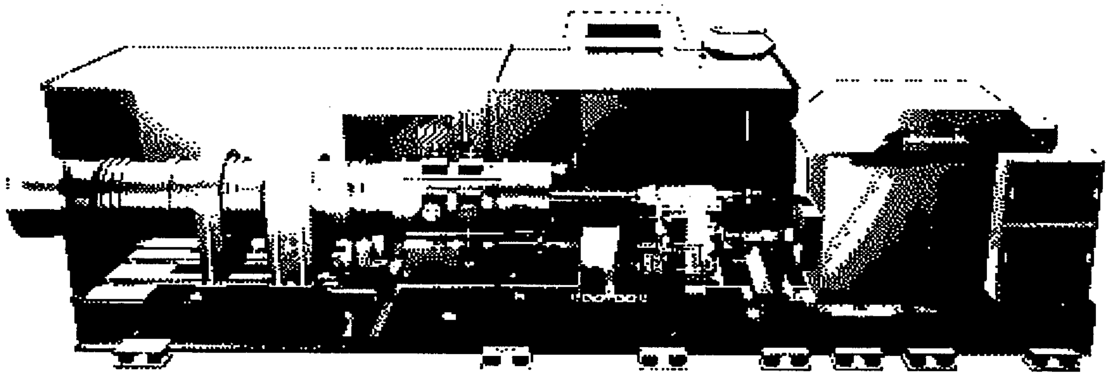


Figure 4 SSGTG Major Components

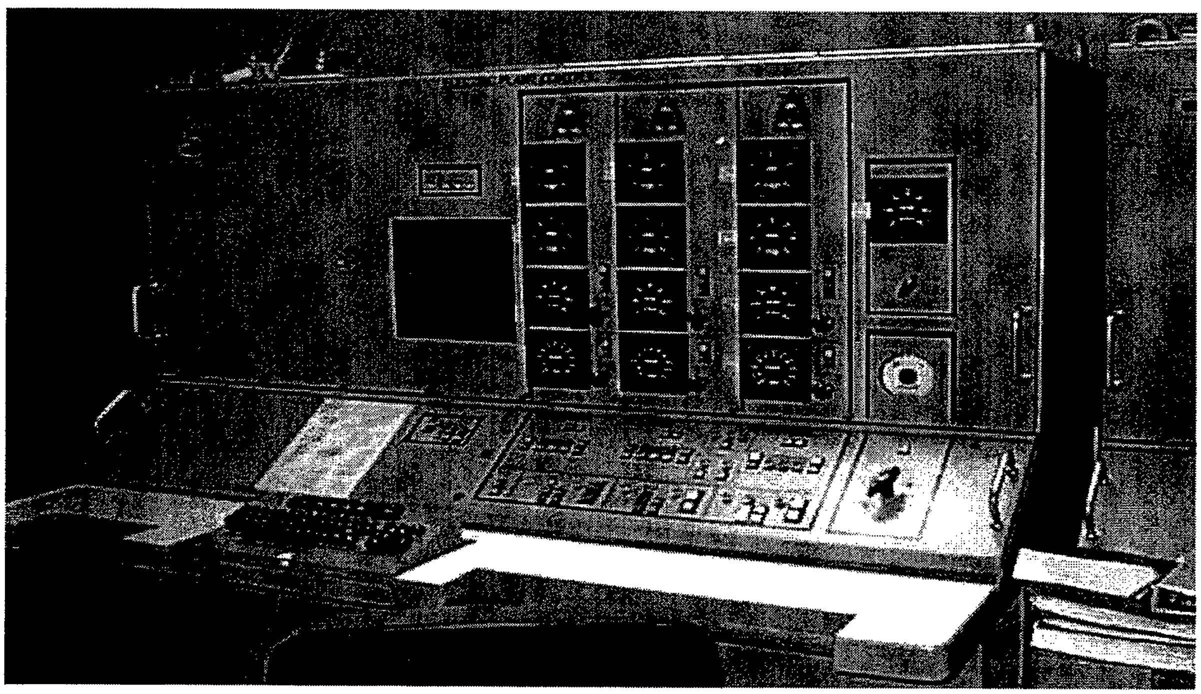


Figure 5 Electric Plant Control Console

Figure 5 shows the gas turbine generator mimic display, electrical distribution

mimic display (both on the sloped panel section), plasma display (to the left) and keyboard (on front shelf).

System Description

The gas turbine engine, reduction gearbox assembly, pneumatic starter, engine lube oil system components, and the majority of the gear/generator lube oil system components are housed in an acoustic enclosure. The generator, LOCOP, and EXCOP are mounted on the base outside the enclosure. Two lube oil coolers are mounted on the module base inside the enclosure. Components of the pneumatic start system are located both inside and outside the enclosure.

Operation

The SSGTG can be started and monitored at the LOCOP. The LOCOP has an electronic control system that sequences and monitors the operation of the gas turbine engine. The SSGTG can also be started remotely at either the switchboard or at the Electric Plant Control Console (EPCC) in the Machinery Central Control Station. Control of the generator voltage and the generator circuit breaker is available at either the switchboard or the EPCC.

Related Equipment

The SSGTG interfaces the ship systems that follow.

a. Gas Turbine Exhaust System.
b. Gas Turbine Combustion Air Intake System.
c. Gas Turbine Cooling Air System.
d. Start Air Supply System
e. Bleed Air System.
f. Control Air System.
g. Halon Supply.
h. Seawater System.
i. Water Wash System.
j. Gas Turbine Fuel Supply System
k. SSGTG Electrical System.
l. Gas Turbine Waste Drain Collecting System.

The service interface connections are made at the enclosure and base assembly.

Capabilities

There are three ship service generators on each ship. Each SSGTG can supply 2500 kW, 4009 amps at 450 VAC, 3 phase, 60 hertz (Hz), with a power factor (pf) of 0.8. Each SSGTG will accept full load immediately after completing the start sequence [12].

Table 2 SSGTG Specifications.

Allison Gas Turbine	Model AG9130, Part No. 23036001
Size	Weight . . . . 68,631 pounds (dry) 70,321 pounds (wet)
	Dimensions . . . . . . .340.75 L x 100.0 W x 133.0 H (inches)
Performance	Power Rating . . . . 2500 kW
	Voltage . . . . 450 VAC, 3 phase
	Full-Load Current . . . . 4009 amps
	Frequency . . . . 60 Hz
	Power Factor 0.8
	Generator Speed . . . . 1800 rpm
	Turbine Speed . . . . .14,340 rpm
	Bleed Air 10%
	Overload Rating . . . . 110% for 0.5 hr @ 0.8pf
Rating Conditions	Inlet Air Temperature . . . . . . .100°F
	Atmospheric Pressure . . . . . . .29.92 in. Hg
	Pressure at Compressor Intake Duct Flange.Total head of 6 in. H2O below atm.
	Pressure at Turbine Exhaust Duct Flange. Static head of 10 in. H2O above atm.
	Relative Humidity 0%
	Bleed Air 0%
	Fuel Lower Heating Value ......18,400 BTU/lbm
	Note: Dimensions are the largest for length, width, and height.

RSVP System Description.

A conceptual overview demonstrating a health monitoring capability for an Allison 501K-17 Ship Service Gas Turbine Generator (SSGTG) and an Air Conditioning Plant is shown in Figure 6. Note that the solid lines are hardwired connections, and the lightning bolts denote radio transmission of data. The abbreviations shown are:

- HCI – Human Computer Interface.
- AP - Access Point.
- SHM – System Health Monitor.
- ICHM – Intelligent Component Health Monitor.

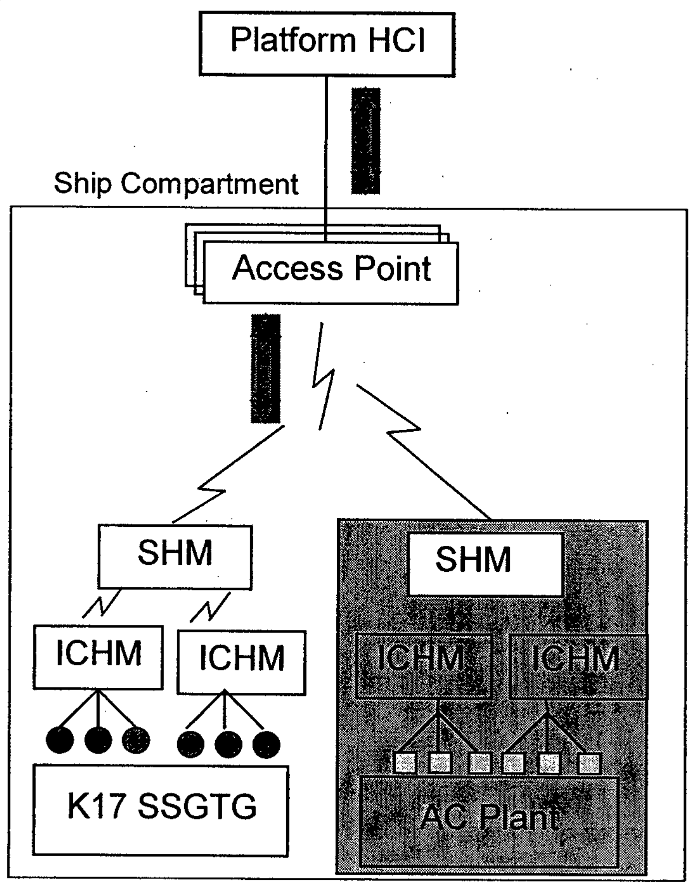
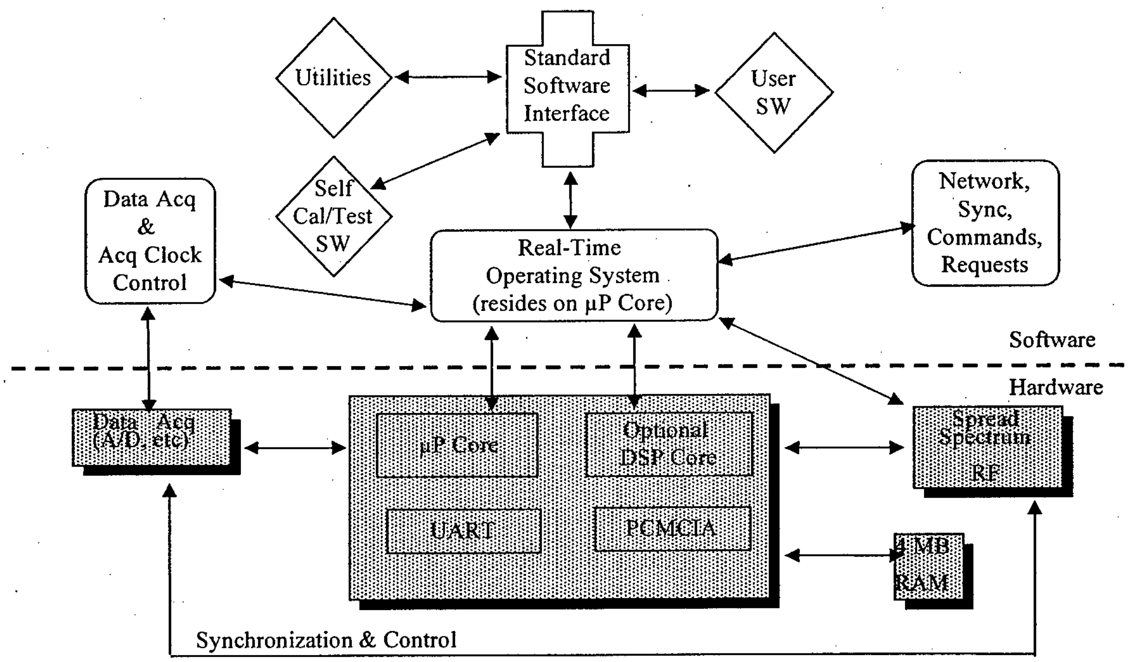


Figure 6. RSVP System Overview

The ICHM, collects the data from all of the embedded sensors. A descriptive block diagram in Figure 7 illustrates the components contained in the ICHM. The ICHM has algorithms to do fast fourier transform analysis, peak picking and averaging of data. The ICHM also archives the data, transmits the analyzed information for eventual display at a Human Computer Interface (HCI) screen at the platform level. The information will be transmitted using RF wireless communication. A radio transmitter goes on top of the ICHM. The ICHM can also support some diagnostic and prognostic algorithms that can alert the operator at the HCI or even effect automatic actions by actuating relays for example. The ICHM is also self-calibrating and will inform the operator if it is malfunctioning. It currently does not match the specifications of the Navy's METCAL or SYSCAL programs, but the ICHM could be revised.



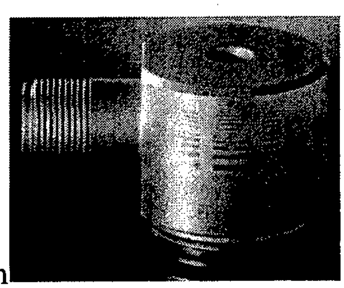


Figure 7 ICHM Block Diagram

The ICHM [13] will contain electronic versions of the technical manual and

design data sheets for the particular machine that it monitors. The continuous data logging must be automatically uploaded to the System Health Monitor (SHM) daily to keep the size of the ICHM reasonable. It is a one-inch cube today as shown in Figure 7.

The ICHM [13] demonstration platform contains accelerometer and temperature sensors with a high dynamic range ~120 dB, high bandwidth 20-40 kHz, dynamic system >1 Hz AC response, and on-chip temperature compensation

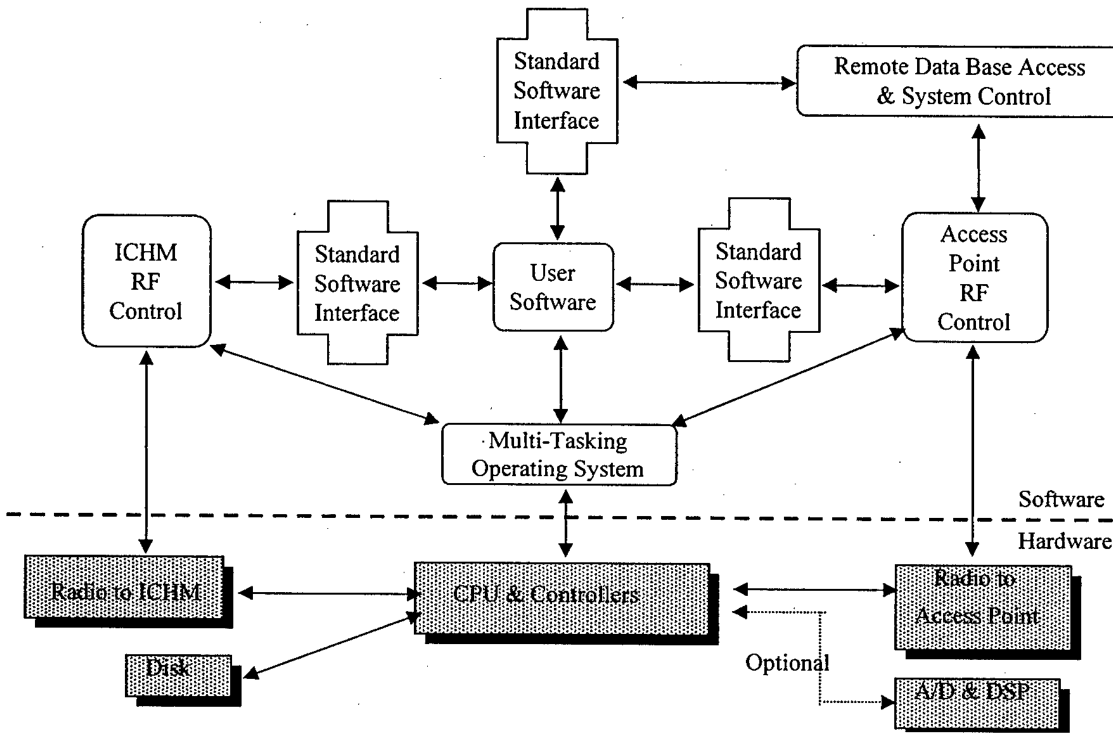


Figure 8 SHM Block Diagram

The SHM software [13] has RF drivers (SHM to AP), RF drivers (SHM to ICHM), communications control, scheduling, data archiving, diagnostic algorithm and data fusion. SHM hardware [13] includes the radio and PC, and all components as shown in Figure 8. Power challenges for wireless communication between the ICHM, SHM, and AP are cost, interference, security, power consumption, and bandwidth.

The basic radio standard chip that is used in today's cellular communications equipment can send one megabyte per second, transmit to ten meters on one milliwatt of power, and could be amplified to get to one-hundred meters at cost of $5.00 each. This radio is not strong enough to transmit through the steel bulkheads of the ship, thus it

relies on existing penetrations to get out of a compartment. The AP for each compartment eliminates the need to transmit through bulkheads, which would require one hundred milliwatts of power and a much larger and more expensive radio. Radio compliant with IEEE standard 802.11 would cost $300.00 per radio chip. It would have twice the bandwidth of the $5.00 radio but is 60 times more expensive. The conclusion in today's technology is that memory and processing is inexpensive compared to bandwidth and power [13].

4.5 Calibration

Sensors need to stay accurate for the life of the ship, since operation, control and maintenance decisions are based on sensor measurements. If DD-21 manning goes down to 95 sailors, this could require some 200,000 sensors shipwide. How can we calibrate all of these sensors? The solution may be a combination of initiatives. The self-calibrating sensor could simply be turned off, and the back up sensors would capture the data. The calibration interval could be lengthened if the designs prove to be robust.

A move away from the tabletop 3666 shipboard calibration standard equipment, which weighs 60 pounds and costs about $60,000.00 each (2 per DDG-51), is the proposed "wearable" calibration device. The 13 pound reader is used to touch measuring points which will take the readings, and machine would have a chip that contains the name, serial number and specifications of the machine.

The reader automatically fills out an electronic calibration form and logs the results. A wireless link can send off the forms to the shore calibration lab for record keeping [14].

4.6 Development

The prototype system integration and testing will be conducted at The Charles Stark Draper Laboratory (Draper) [9]. Upon completion, the prototype RSVP system will be installed and demonstrated at the Land-Based Engineering Site (LBES) at NSWCCD Philadelphia. The land-based demonstration will exercise and test all aspects of system operation and functionality from the sensor level to the Human Computer Interface (HCI).

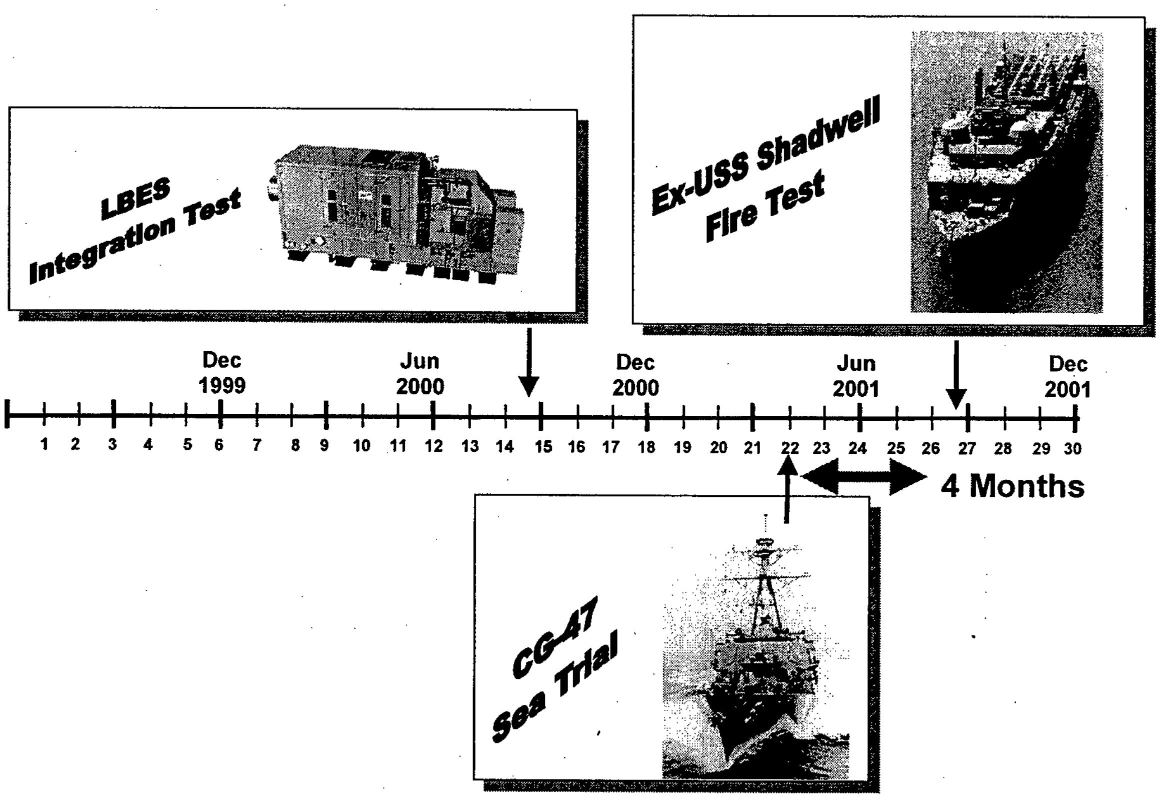


Figure 9 RSVP Testing Timeline

During the Shipboard Demonstration Phase, the RSVP laboratory prototype system will be installed aboard two ship platforms: an active CG-47 class ship and the Navy's Damage Control Training and R&D facility, the ex-USS Shadwell. The CG-47 demonstration will encompass monitoring and assessment of selected aspects of two compartments: Auxiliary Machinery Room #1 (AMR1), and Main Machinery Room #1

(MMR1). AMR1 and MMR1 were chosen because they are representative of ship compartments requiring the highest level of monitoring. The at-sea demonstration will monitor the environment, machinery, structure, and personnel. Machinery monitoring will target the Ship Service Gas Turbine Generator (SSGTG) in MMR1.

The demonstration on the ex-USS Shadwell will exercise the environmental, structural and personnel monitoring in a damage control situation, that would otherwise be impractical to induce on in-service combatants. The ex-USS Shadwell testing will be conducted in conjunction with the final DC-ARM program demonstration. The ex-USS Shadwell demonstration will focus on monitoring and assessment of smoke, fire, flooding and personnel location and provide internal compartment level situational awareness. Information and supporting data, for both demonstrations, will be provided to operators through an HCI located elsewhere on the ship.

RSVP will enable the reduction of an additional 34 crewmembers beyond current Smart Ship Manning, while enhancing operational performance. The projected payoff supports DD-21's goal of a significant reduction in manning levels by permitting safe and effective operation of the ship through the automation of situational awareness, machinery health and damage assessment functions. The O&S cost avoidance for the DD-21 ship class is expected to be minimum of approximately $2.5B [9].

4.7 Transition Plans

The primary transition target for technology insertion is DD-21. DD-21 has identified funding for transition of RSVP technology into the DD-21 design.

Backfit: The technologies being utilized by RSVP lend themselves to backfits using an open architecture approach and leveraging industry standards. The wireless communication aspects are well suited for installation aboard existing platforms. Potential backfit classes are CG-47, DDG-51, and CVN-68.

Forward Fit: Potential forward-fit classes are LPD-17, LHX, and CVX, RSVP POM inputs were provided, by request, to the CVX Design team, for the entire ship

construction phase. CVX requested this information for possible transition of an RSVP system directly to the next generation carrier [9].

Now that the shipboard equipment functions and the RSVP technologies associated with those functions have been presented in detail the next chapter describes the general process for analyzing the tasks related to operation of shipboard equipment and how RSVP sensors and the information presented by RSVP machinery HMS will support that.

Chapter 5 Information Requirements determination Process

This chapter describes a general methodology for implementing automation systems aboard ship. The process analyzes current information and tasks that are required for the machinery to be operated within a mission context, to allow the system to perform its intended purpose. The same analysis is applied to the propulsion and electrical machinery of the DDG-51 with a conceptual automation system included. Scenarios of mission context and subject matter expert interviews are used to determine the information and tasks required for the automated system to satisfy the intended purpose of the machinery. The current and conceptual processes are compared and tasks are then allocated to automation, eliminated or retained as necessary human functions [16,17,18,19,20].

5.1 Approach to Defining Information Requirements through Cognitive Engineering

This approach is the author's opinion of how to determine the tasks and information required to perform those tasks in a shipboard machinery monitoring and control context. Since there are no exact answers as to how to implement automation technology into shipboard systems, this is just one approach. The overall method is validated to some degree, by basing it on the teachings of human or cognitive engineering experts. The interaction between man and machine is multifaceted and requires consideration of thought, motor skills, and the ergonomics of the systems. The method is set forth in the following steps.

1. Determine automation guidelines by setting the manning reduction target or goal, reviewing the operational requirements and how they will be met by an automation system, and by making baseline assumptions about what criteria tasks are to be chosen for automation.

2. Develop detailed operational scenarios based on available technical and policy

information, expert interviews, and experience. The scenarios give context to the designers to understand the functions and information that must be captured by the automation system, and to the interviewees to understand the concept of the automation system. The scenarios shall include varied levels of intensity from routine to extreme, for example:

- Routine Operations
- Special or Infrequent Operations
- Casualty or Emergency Operations
- Plant Recovery and Maintenance Operations

3. Determine the philosophy for functional allocation of tasks for either a crewman (human) or machine. For example a philosophy might be to automate any task that has a frequency of greater than once per watch or per day. The tasks for automation then must be evaluated based on how manpower intensive they are, so that the most time saving measures are adopted first. Be aware that tasks include the mental tasks of analyzing and reasoning in addition to the obvious physical activities.

4. Combine the scenarios, interview results, and functional allocation guidelines to determine the sensor and information requirements for capturing the proper operation of the machinery with the HMS technology installed. Determining necessary data transfer rates, refresh rates, and availability and extent of logging the data must further define the information requirements.

5. Determine how to make the most efficient and effective use of the raw data to provide useful information for automatic and human based control of the machinery (SSGTGs). For example the data can be condensed into time averaged data points and displayed as trend curves. The information can be analyzed by diagnostic and prognostic algorithms for making recommendations to the operator or for taking action automatically.

6. Determine the most effective Human Computer Interface (HCI) to effectively and accurately display the information and allow efficient decision making and control functions. For example when and what information should prompt operator alerts, warnings and or recommendations. In some instances automatic protective action may be the best choice.

7. Evaluate results against goals and repeat the process if necessary to refine the design.

5.2 Detailed Process Description

Determine automation guidelines

A detailed review of the machinery technical manuals, shipboard operating procedures and maintenance manuals will illustrate the machinery (or system of interest) operational requirements. The number and variety of tasks involved with operating the machinery under various conditions will be determined. Some baseline assumptions must be made such as any task that is done more than once a day will be automated or perhaps those done every 48 hours if a more drastic manning reduction is desired. Each task must then be weighed as to how much time is saved. Those task that save the most in man-hours will be automated first.

Automation guidelines can begin by setting a manning reduction target. In the case of the machinery HMSs such as RSVP the sponsor (ONR) has estimated that a reduction of 34 men from the crew is achievable beyond the savings already realized from the smartship initiatives. This target should only be a starting point and not drive the design process, although having a goal can initiate and motivate the process of crew reduction as was the case when a program manager said "The 21st century destroyer should have a crew of only 95" and kicked off the DD-21 manning concept. Crew reductions should be based on optimizing the systems and technology in the context of use, and not simply to meet a target manning level. Never forget that eliminating a task is always an option to consider before automating it.

The basis for this study is the Arleigh Burke or DDG-51 class U.S. Navy destroyer. The current average manning level of the DDG-51 is 322, with a portion of those men allocated to operation of the Allison 501K-17 and 34 Ship Service Gas Turbine Generators (SSGTG). The goal is to allow unmanned operation of the SSGTGs through automated machinery sensors for monitoring and control functions rather than a dedicated roving watchstander taking log readings on the machines hourly. Some skilled SSGTG technicians will still be required for on scene expertise and maintenance or further trouble shooting of a sensor identified anomaly. The categories of manning for several workload elements of operational readiness are summarized in Figure 10. [15] Figure 10 illustrates the way US Navy manning analysis has been approached in the past. In many ways the specialization of ratings is sub optimal for the most efficient use of manpower.

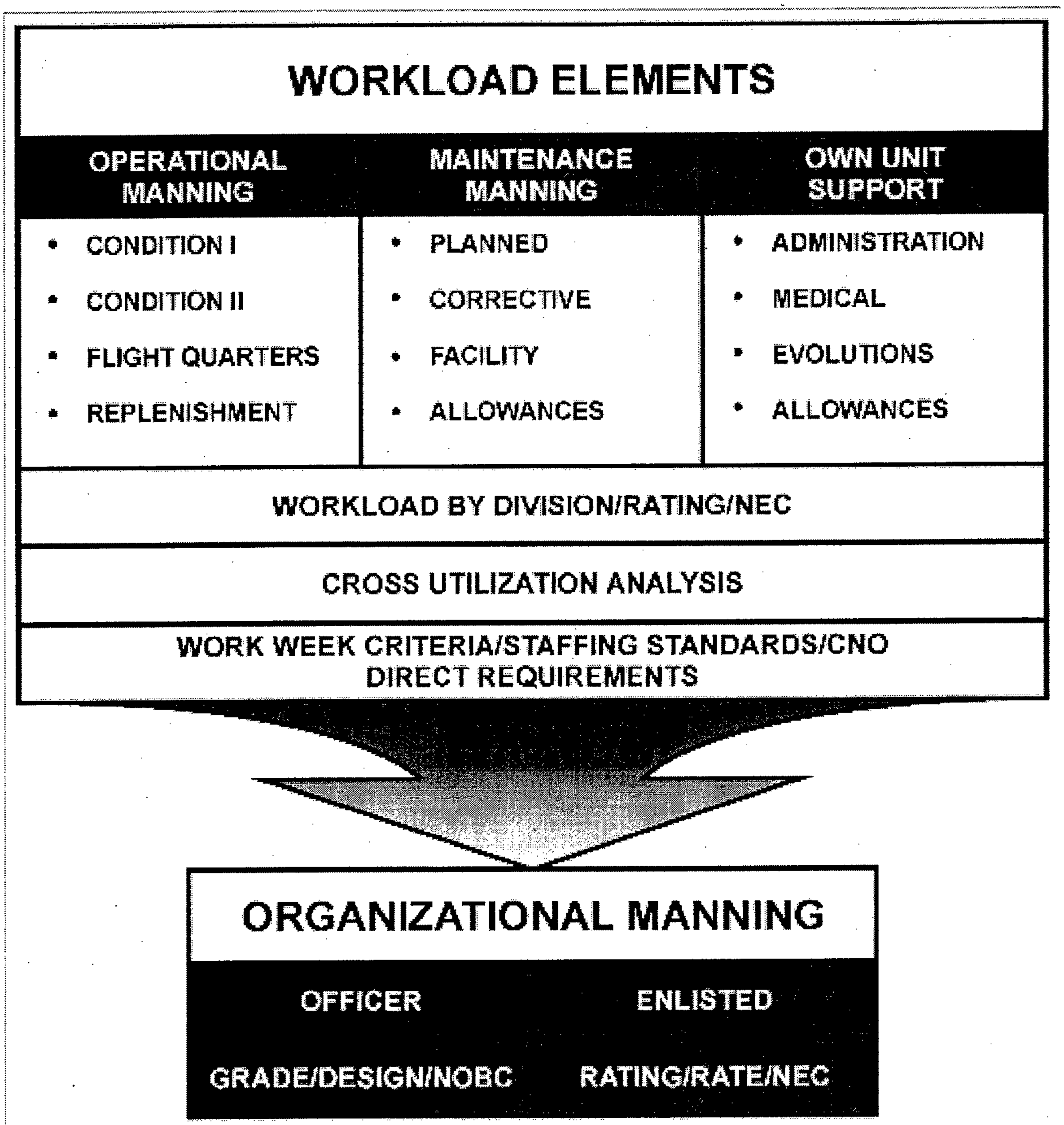


Figure 10 DDG-51 Workload Elements

Baseline assumptions for this automation effort are that the machines will run safely without any human attention, with the exception of an HCI SSGTG Console watch. The Console Watch will be alerted of any abnormalities and given suggested corrective action as necessary. All periodic tasks will be evaluated for automation, elimination, or extension of periodicity to reduce the human workload.

Develop Detailed Operational Scenarios and Conduct System Expert Interviews

Developing scenarios helps the understanding of the system in the context of its use, and helps to illustrate how the automation might be optimized. Operational scenarios are based on available technical and policy information, expert interviews, and experience. The scenarios include a variety of intensities from routine to casualty operations. A good starting point is to largely base the scenarios on operating manuals and on the Technical Manual for the SSGTG, however, to automate by simply mapping from current systems processes, is not the best way because some of the current system requirements may be sub optimal or no longer relevant. These manuals detail the system description, operation, maintenance, trouble shooting, sensors, indicating lights, and parts lists. The manuals and their intended use are described in detail in Chapter 6. The scenarios will include Routine Operations, Special or Infrequent Operations, Casualty or Emergency Operations, and Plant Recovery and Maintenance Operations.

Routine Operations are normal underway periods with standard SSGTG operating configuration such as Port and Starboard SSGTG on line sharing load at approximately 60% of full load. Routine watchstander duties are to start, monitor, adjust load and stop the machines. Special or Infrequent Operations are tasks that occur infrequently so that typical operator experience is insufficient. These tasks must be performed carefully step by step in accordance with the technical manual and ship operational doctrine procedures.

Casualty or Emergency Operations are conditions usually requiring rapid simultaneous startup of the standby SSGTG and securing of the afflicted SSGTG. The immediate actions for many casualties are spelled out in the operating procedures and are required to be memorized by the operators so that the actions will be done without hesitation to place the plant equipment in a safe condition while still supporting the mission capability as much as possible.

Plant Recovery actions are those follow-up actions and analysis required after a casualty, to restore the maximum safe level of plant operation and to concisely determine the corrective action and parts needed to restore the afflicted engine to full service.

Maintenance actions are defined in the technical manual as well as the planned maintenance manual. The maintenance requirements define the man-hours of work, the

personnel and level of expertise required, and parts necessary for routine planned equipment maintenance or replacement. These maintenance items can be recommended by the system when diagnostics indicate that it is time. The navy is moving away from the scheduled or planned maintenance system to save time and money associated with unnecessary maintenance by using condition based maintenance.

The shipboard operator's experience and understanding of the environment in which the system is to be used must be included in the early design stage, for maximum efficiency and contribution to overall mission once the system is fielded aboard ship. There are too many examples of a dysfunctional haze gray box that was supposed to revolutionize a particular aspect of the ship's mission. Worse yet are those systems that require more man-hours to maintain than the alleged time savings they enabled. One operator's view is not an accurate representation of the best design space.

This necessitates a detailed survey to gather expert opinions of a cross section of operators. Survey Development requires determining the number of questions and appropriate level, to be used in the survey. One must decide whom the system experts are and who is to be surveyed to represent this level of expertise. Typically a cross section of experts with varying levels of knowledge will be interviewed. Each group may need to be given relative weightings on their answers to capture the importance of one level of knowledge over another. Details of the survey developed and used in this thesis are discussed in Chapter 7.

Determine Philosophy for Functional Allocation

Functional allocation of tasks for either a crewman (human) or machine requires that all tasks necessary to operate the SSGTGs be broken down into the simplest steps. Each step is evaluated for allocation to a human or machine. Be aware that "tasks" include analyzing and reasoning in addition to the obvious physical activities.

The RSVP system is an expert system if the definition is restricted to "a system that a human recognizes as behaving like an expert in some domain, and that provides information, advice or assistance to the human."[17] The proper design of this system requires an in-depth knowledge and understanding of the tasks that are to be supported

and the environment and context in which those tasks are to be performed. The tasks must be decomposed into specific steps in a logical sequence to achieve an end result.

The SSGTG Technical Manual Operations section has the basic functions already listed as steps of a procedure to operate the engine manually. This is an excellent starting point for determining tasks for functional allocation, however it is insufficient in three areas. First it fails to capture all of the cognitive (analyzing and interpreting) activities that the human does while progressing through a procedure. The thinking steps must also be added to the task list. Secondly, the Technical Manual only addresses the number of scenarios (n) that the manufacturer envisioned and engineered. It is the "n+1" events that can make a design perform poorly and possibly result in equipment damage and danger to the crew and to the ship. Lastly, it is not sufficient to simply automate the current human functions that are listed; rather the designer should look for the most efficient way to achieve the intended end results.

Combine Scenarios, Expert Interviews and Functional Allocation to Determine Information Requirements.

Information requirements answer the question of what sensors and information are necessary for capturing the proper operation of the Allison 501K-17 and 34 SSGTGs with fewer crewmen on watch and the RSVP technology installed. The information requirements must be further defined by determining the necessary data transfer rates, refresh rates, availability of the data and the extent of logging the data.

Since RSVP is essentially an information tool, the designer must determine what readings are essential, how they should be displayed, what combinations of readings will mean and what, if any, recommendations should be made or automatic actions should be taken. The RSVP system shall collect, sort, condense trend and integrate the data to aid the Human in decision making. The system must be able to chronologically determine the sequence of events during a fault (i.e. fast enough to separate and put a time stamp on its recorded readings). Keep in mind that RSVP is to be an operator aid and as such should help the human with the processing and interpretation of data. A typical human process

flow in an on-watch situation is a progression from detection of a problem (alerted), to system status determination (data gathering), to interpretation of data, to deciding to take action, and which action to take. This on watch decision making is a combination of different decision processes [21]. Knowledge based behavior, (according to Jens Rasmussen, well known behavioral scientist), is a decision process that involves the full chain of causal reasoning, including interpretation and evaluation. If a procedure is selected based on the interpretation of the system state, then the watchstander enters rule-based behavior. The memorized instinctive actions of a watchstander are skills-based behavior. The design of the operator aid must consider all of these behavioral factors so that the diagnostic and prognostic algorithms of the machinery health monitoring and control system will enhance the operator's awareness of the system state, and improve the operator's performance in determining the best course of action to take.

Determine Efficient Presentation of Data for Information and Control

Determine how to make the most efficient and effective use of the raw data to provide useful information for use in automatic and human based control of the SSGTGs. The data can be condensed into time averaged data points and displayed as trend curves. The trends can be displayed over time to give an idea of system health. The goal is not to send data to the operator rather it is to send meaningful information and some conclusions and recommendations to the operator. In some cases the recommendations should come with automatic action to keep the ship supplied with electrical power and to place the plant equipment in a safe condition. In other cases recommendations are sufficient.

Develop Efficient Design Ideas for the Human Computer Interface

Determine the most effective Human Computer Interface (HCI) to effectively and accurately display the information and allow efficient decision making and control functions. For example when and what information should prompt operator alerts, warnings and or recommendations. In some instances automatic protective action may be

the best choice, either fully automatic or requiring operator acknowledgement first.

In specifying the HCI, common flaws in HCI design should be avoided by using the lessons learned from design failures in the past [21] such as the Three Mile Island reactor accident in 1979. Some poor HCI design elements contributed to the misdiagnosis of the problem and subsequent human errors that compounded the problem. Examples include an excessive amount of summary alarms resulting in operator confusion, an incomplete scale of readings resulting in a loss of data when off-scale, and a history of faulty indications which prompted the operators to doubt their indications.

At the platform interface (top level) designers must decide if the system will recommend action, take action, display alternatives and or display the resultant effects if the action is taken. The integration process from automation system concept to fleet introduction is a daunting task since it encompasses so many design, policy, and engineering areas as illustrated in Figure 11. [15] It is important to keep the goal in mind, which is to enhance total system performance while reducing operating costs and lifecycle costs.

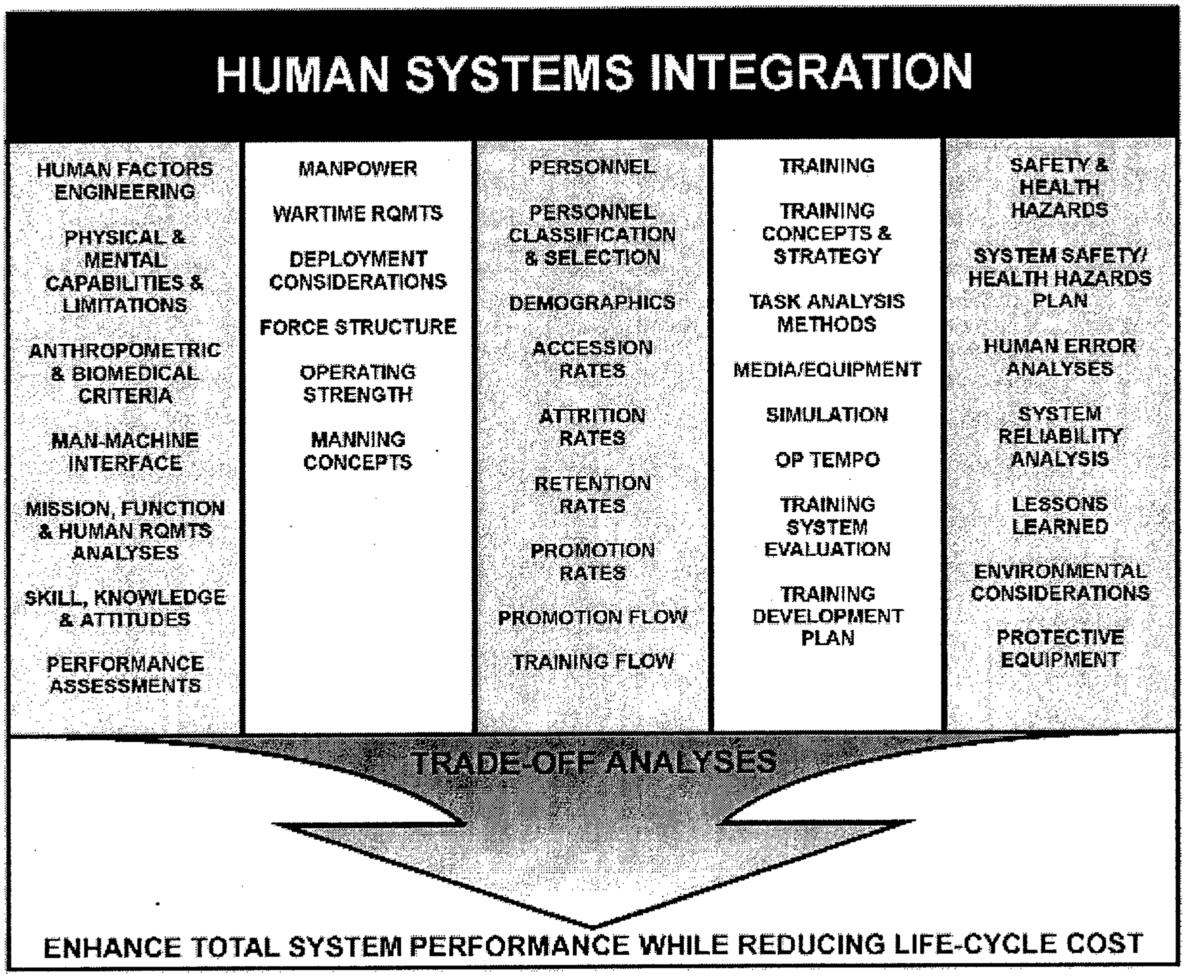


Figure 11 Human Systems Integration Elements

In summary this chapter laid out a sequential method to properly implement an automation system aboard ship. The second major step after deciding on automation guidelines and philosophies is to develop detailed operational scenarios to capture the context in which this system must operate. The sources for developing the scenarios are described in the next chapter.

Chapter 6 Scenarios and Sources for the task descriptions

This chapter describes the technical publications used to develop the scenarios and task descriptions associated with operating the Ship Service Gas Turbine Generators. They include normal operations, casualty actions, troubleshooting and maintenance actions, as well as inspection requirements. The second major step of the information requirements determination process is to develop detailed operational scenarios and conduct interviews.

The scenarios are based on information from technical publications, operating manuals, expert interviews, and experience. The scenarios and interviews give context of use and give operator's and engineer's perspectives to the designers.

Scenario categories include routine operations, special/infrequent operations, emergency/casualty operations, and maintenance operations. The manuals described in this Chapter are:

- Technical Manual for the SSGTG
- Operations Manual for the SSGTG
    - Engineering Operational Procedures (EOP)
    - Engineering Operational Casualty Control (EOCC)
- Engineering Control System Equipment Guide
- Litton's CG-47 Class Machinery Control Upgrade
- Planned Maintenance Manual for the SSGTG
- Marine Turbine Inspection Handbook for the SSGTG

The scenarios that were developed are presented in the tables at the end of this chapter.

6.1 Technical Manual for the SSGTG

The technical manual (S9311-CQ-MMA-010 0910-LP) is a five volume set for the Model AG9130 Ship Service Gas Turbine Generator Set. This generator is installed on the DDG-51 class ships. The manual is for personnel who operate, maintain, and/or repair the SSGTG.

Ships, training activities, supply points, depots, naval shipyards, and Supervisors of Shipbuilding are requested to arrange for the maximum practical use and evaluation of NAVSEA technical manuals.

Chapters 1 through 4 provide general information and safety precautions, information on the operation of the AG9130 SSGTG, functional description of how the system operates, and description of scheduled maintenance.

Chapter 5 provides troubleshooting procedures, in tables and text, to help locate and remedy malfunctions in the AG9130 SSGTG at the organizational level. It includes numerous illustrations and electrical and mechanical schematics. These procedures cover the following SSGTG components:

a. Local Control Panel (LOCOP).
b. Gas Turbine Engine.
c. Generator and Redundant Voltage Regulator.
d. Reduction Gearbox.
e. Gas Turbine Lube Oil System.
f. Reduction Gearbox/Generator Lube Oil System.
g. Fuel and Deck Drain System.
h. Seawater System.
i. Pneumatic Start System.
j. Bleed Air Control System.
k. Cooling Air System.
l. Water Wash and Anti-icing System.

m. Halon and Fire Detection System.

n. Skid Electrical System.

o. Lighting System.

p. Floor Drain System.

The corrective maintenance chapter (6) consists of procedures necessary to restore failed components to an operational condition. The corrective maintenance procedures are written in a format similar to that of Maintenance Requirement Cards (MRCs) of the Planned Maintenance System (PMS). A complete list of alignment and adjustment procedures is provided as well as all information necessary to adjust or align components. A description of any test equipment or special tools required is included.

A list of corrective maintenance and step-by-step procedures necessary for removal and replacement of components is also provided.

Chapter 7 has the illustrated parts breakdown for the AG9130 SSGTG, and has instructions on how to use the information. Names and addresses of Federal Supply Code Manufacturers are also listed.

Chapter 8 provides the information and procedures for installation and shipboard testing of the AG9130 SSGTG. Procedures for shipping and storing major SSGTG components are also included.

6.2 Operations Manual for the SSGTGs

The Operations Manual or Engineering Operational Sequencing System (EOSS) is developed by the Naval Surface Warfare Center Carderock Division (NSWC-CD) Philadelphia, and approved by NAVSEA for use aboard ship. The following description is based on unclassified excerpts from the EOSS for the SSGTG. The EOSS contains detailed information that allows the navy crew to safely and efficiently operate the GTG under various conditions and transitions from state to state. This document is essential in understanding the scope of operations and the need for sensors and control systems when determining how a smart sensor system would be implemented.

Description of EOSS

The EOSS consists of procedures, charts and diagrams required for operation of a ship's propulsion plant. It consists of two parts; the Engineering Operational Procedures

(EOP) and the Engineering Operational Casualty Control (EOCC) procedures.

The EOP consists of technically correct written procedures for all levels of supervision, status charts and diagrams required for the normal transition between steady state operating conditions. The EOP is configured according to the individual ship's engineering plant configuration and degree of plant control (i.e., fully automated, partially automated, or non-automated).

Each Status Chart (SC) contains information, or a means to maintain information current, in support of plant status changes and normal steady state operation. Use of SCs will ensure that exact plant status is readily available at all times and the supervisor can determine the effect that a specific action will have on the plant. An electronic equivalent of the SC must be provided by the machinery HMS for continuous situational awareness.

System Diagrams are provided for systems within the propulsion plant. These diagrams will show all valves in a specific system. The HMS will provide the ability to look at system diagrams on screen, and if the components are remotely operated then the HMS screen will also allow control of the components in the system diagram.

The EOCC consists of technically correct, logically sequenced procedures for responding to and controlling commonly occurring casualties. When properly followed, these procedures result in the placing of the propulsion plant in a safe, stable condition while the cause is being determined. After the cause has been discovered and the problem corrected, provision is made for casualty restoration. The determination of the casualty and the recommended or automatic actions will be provided by the diagnostic and prognostic algorithms within the HMS software.

Objectives of EOSS

To provides safe, technically accurate and standardized operational and casualty control procedures tailored to the individual ship's configuration. Use of EOSS increases equipment service life and minimizes casualty occurrence by ensuring that each system or component is properly aligned, operated and secured. EOSS also ensures that shipboard training for machinery operation is standardized. These elements must be incorporated in the design of a machinery health monitoring and control system. EOSS

coverage is provided for the normal transition between steady state operating conditions, casualty restoration, and the most commonly occurring casualties. Designers, manufacturers and crewmembers are encouraged to write procedures for evolutions for which EOSS has not addressed.

These procedures are also used for walkthrough and live drill watch training. With a highly automated engineroom, watch training will still occur however, the operator will recall the drawing and the components from the screen display, rather than the physical location of components in the plant.

Use of EOSS Procedures

The level of proficiency of the watchstander will determine how a particular EOP procedure will be "Strictly adhered to as written". Repeated use of EOP to operate the propulsion plant will increase the watchstander's level of proficiency. As a result, the manner in which the watchstander strictly adheres to the EOP will change. After being ordered to carry out a section of a procedure (aligning for operation, starting, stopping, etc.) the inexperienced watchstander shall read the entire section before accomplishing any of the actions specified. Then the watchstander shall read each action step in the section immediately before it is accomplished. After all required action steps in the section are accomplished, the section should be re-read to ensure all required actions have been accomplished in the proper order. The more proficient watchstander is still required to review each section before any actions are carried out. However, several action steps may be accomplished before referring to the procedure. The section should be re-read after it is accomplished. At the highest level of proficiency, the watchstander will utilize the procedure as a checkoff sheet, ensuring that all required actions are accomplished in the correct sequence. However, no matter how experienced or knowledgeable the watchstander becomes, the EOP should be reviewed prior to accomplishing the required procedure and it should be re-read again after the procedure is accomplished to ensure that all required actions have been completed. The smart operator aid can assist by displaying required procedures, keeping track of steps accomplished and or prompting the operator to take action.

The philosophy for "strictly adhering" to EOCC is different because to recover from a casualty:

1. The Symptoms/Indications, Possible Causes and Possible Effects of a casualty must be known and understood.

2. The Controlling and Immediate Actions sections of EOCC must be memorized.

3. The Stopping during a Casualty sections of designated EOP procedures must be memorized.

4. The location and operation of designated valves and components must be fully understood.

Elements 1 through 4 are requirements that the automation system must give operator support for. The HMS must also allow rapid identification, communication and resolution of any deviations from the programmed procedures when it is determined that the procedure as written no longer applicable or efficient such as ship alterations and out of commission equipment.

Casualty Response Procedures provide an overview of the casualty response for each specific casualty, and contains the following sections:

a. Symptoms/Indications, Possible Causes and Possible Effects which are arranged vertically from the top in the order of probable occurrence.

b. Controlling Actions which detail the sequential steps to be taken to stabilize an abnormal situation and prevent an actual casualty.

c. Immediate Actions which detail the sequential steps necessary to stabilize, gain control and stop the cascading effect of the casualty. Note that the watchstander should not proceed to Immediate Actions until notified that a casualty has occurred, and controlling Actions and Immediate Actions are intended to be memorized by the watchstander.

d. Supplementary Actions which detail the sequential steps to be taken by watchstanders in stabilizing the engineering plant and securing equipment so that the engineer officer can determine whether the equipment may be restored or the plant secured for repairs.

e. Restore the plant to normal after casualty is over.

An equivalent to these sections should be established within the machinery HMS

software and be tailored for the best way to deal with casualties now that the system has a monitoring and control upgrade.

Due to the large number of possible equipment combinations and steaming conditions that could exist when a casualty occurs, certain conditions have been established as a basis for development of EOCC for each class of ship. Standard assumptions for the plant conditions are made based on "normal steaming" lineups.

Watchteam Communications

The need for correct and standardized communication procedures cannot be over-emphasized. Communication procedures, discussed in the following paragraphs, should be used in conjunction with EOSS. The following chain of command must be known and followed in the context of the system as it is today. The chain of command will shrink as crewmembers functions are automated.

a. Engineering Officer of the Watch (EOOW) - Receives orders from, and reports to, the Officer of the Deck (OOD) and/or Combat Systems OOW (CSOOW) as appropriate.

b. Space Supervisor - Receives orders from, and reports to, the EOOW. Gives orders to, and receives reports from, watchstanders in the area(s) of his/her supervision.

c. Watchstander - Receives orders from and reports to the Space Supervisor and/or the EOOW.

The following elements of good communication are essential, and should be considered in the HCI design for messaging and all station alerts.

a. All orders and reports will be addressed to watchstations rather than by name to individual watchstanders.

b. Communication circuit discipline will be observed.

(1) Keep communications brief.

(2) Communication circuits to be used for official communications only.

(3) Do not interrupt ongoing communication except in an emergency.

(4) Slang terms or locally devised code signals will not be used.

c. It is essential that personnel are articulate, brief, calm and possess a good

understanding of engineering terminology.

d. Call the station and report the message without delay.

All of the elements of the EOSS must be considered in the automation of a system , and every effort should be made to communicate designers and EOSS authors during the development of new systems.

6.3 Engine Room Control System Equipment Guide

This Engine Room Control System Equipment (ECSE) guide was reviewed to give an idea of what the state of the art control systems being used aboard ship today look like. The ECSE is a prime example of current state-of-the-art automation technology, which provides the monitoring and control of the main engines and gas turbine generators as well as all associated auxiliary equipment from a single screen. The ECSE gives the console operator the capability to call up other screens and information all from a touch screen application. The Purposes of the USS Ticonderoga (CG-47) class engineering control system equipment upgrade includes the following:

- An Upgrade in Technology
- Reduced Manpower Requirements
- Better Survivability
- Imbedded Training Capability
- Built in Integrated electronic Technical Manual (IETM).

The main screen provides a "top level" overview of the entire plant, with subsections for main propulsion, electric plant, auxiliaries, and damage control as shown in the Figure 12 below. With a click on one of the main system icons a pop-up "system level" operating screen will appear for more detail, as shown in the damage control screen example. Figure 13

The popup permits detail, larger scale parameters, and includes an overview of the selected system. Any system can be selected using the buttons on the top line or by window select buttons on the bottom right.

The top line also has automated selection buttons for the embedded training status (training, off line, or in control) and contains "one-button" selection to declare ship condition such as restricted maneuvering, and General Quarters. These selection buttons permit ship-configurable control system responses in accordance with standing orders, to happen automatically or to alert all stations of the declared condition. Revisions are made by CHENG access only, and machinery line-up change authorization is controlled by the C.O.

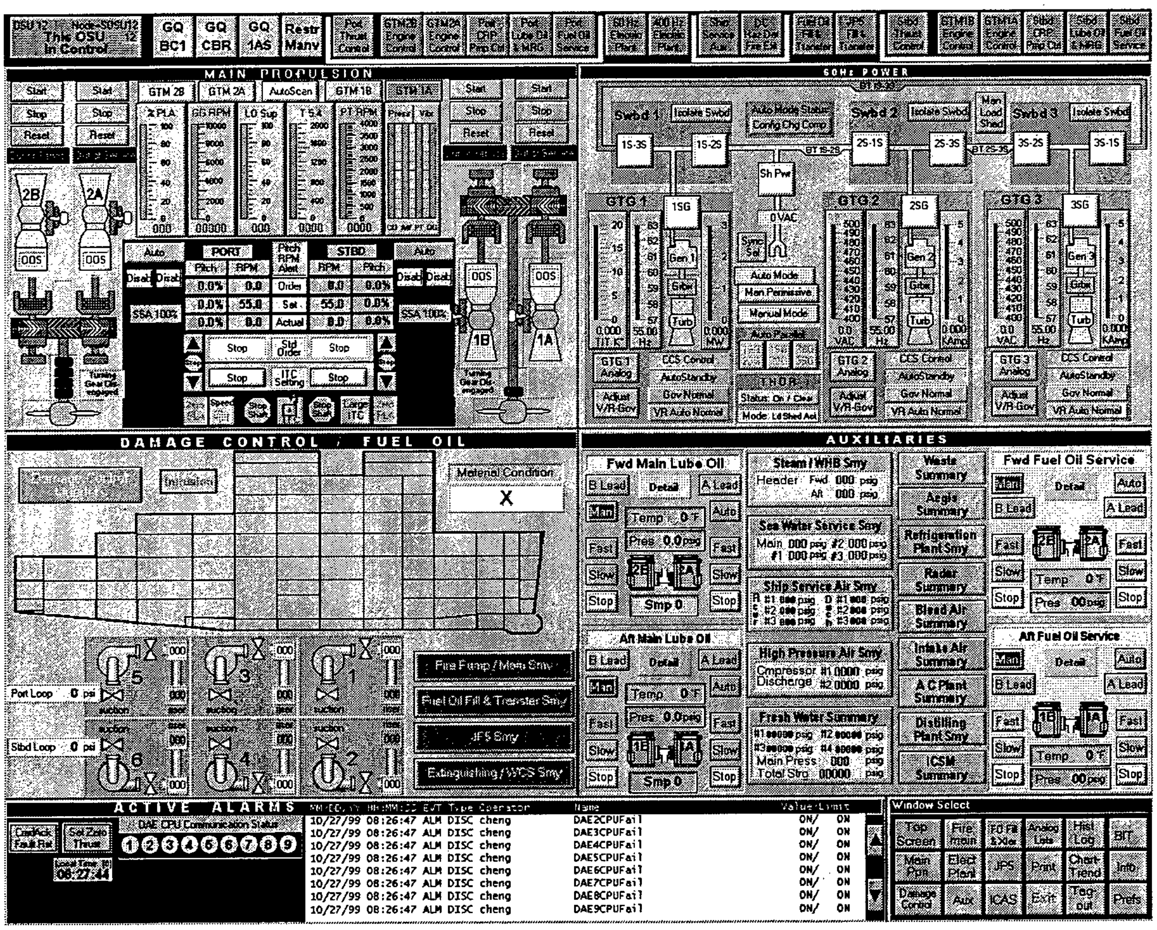


Figure 12 Litton Marine Engineering Control System Equipment Screen

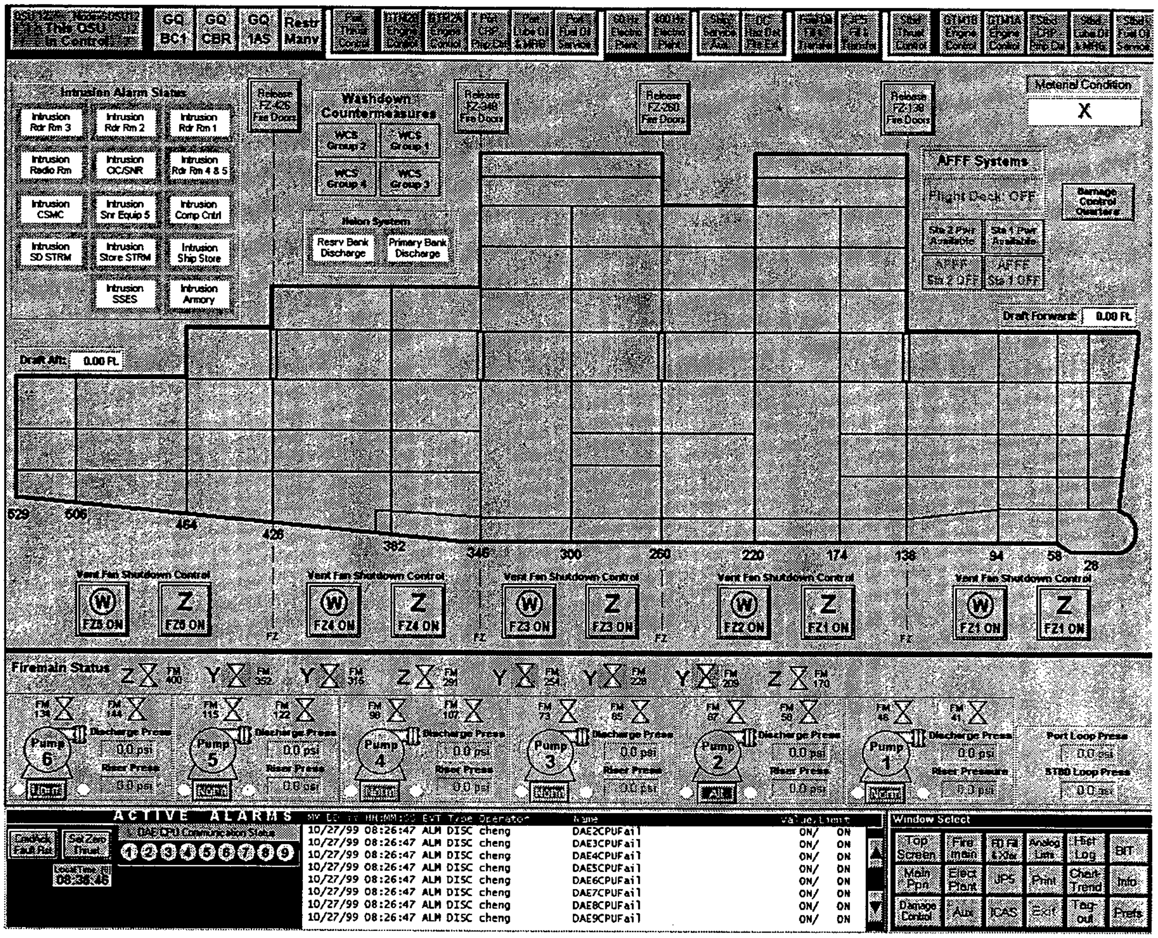


Figure 13 Litton Marine Engineering Damage Control Screen

The bottom left of the screen contains control transfer indicators for 18 transferable functions, which are connected to the Integrated Bridge System consoles for thrust control, critical alarms, non-critical alarms, built-in test (BIT) alarms, operator alert (audible or flashing), engine order telegraph bell, selected alarm acknowledge from alarm grid, and active and unacknowledged alarm information.

The bottom right has 18 possible screen selections. They are: top screen, main propulsion, damage control, fire main, electric plant, auxiliaries, fuel oil fill & transfer, JP5, ICAS, analog lists, print, spare, history log, chart trends, tag-out status, BIT, and information preferences.

6.4 Planned Maintenance System and Related SSGTG Manuals

The "Navy PMS document for Gas Turbine, Boats & Coast Guard Vessels" contains all Planned Maintenance System (PMS) requirements for all gas turbine powered ships, boats and Coast Guard vessels in the Ships' PMS text database. This document includes all Maintenance Index Pages (MIPs) and Maintenance Requirement Cards (MRCs) for these activities. Each Maintenance Index Page (MIP) is an index of a complete set of Maintenance Requirement Cards (MRCs) applicable to a ship system, subsystem or equipment. Each MRC provides detailed procedures for performing maintenance requirements and describes who, what, how and with what resources a specific requirement will be accomplished. This information is essential in designing any automatic maintenance functions such as diagnosis, recommendations, predicted time to failure, and automatic planning of maintenance and ordering of parts.

In addition, other good references are the Maintenance and Material Management (3-M) Manual, (OPNAV INSTRUCTION 4790.4C). The 3-M System is the nucleus for managing maintenance aboard all ships and applicable shore station equipment. This system provides all maintenance and material managers throughout the Navy with the means to plan, acquire, organize, direct, control and evaluate the manpower and material resources expended or planned for expenditure in support of maintenance. The Standard PMS Materials Identification Guide (SPMIG) database which provides part numbers and ordering information for material contained on MRCs in the test equipment, materials, parts and tools block. The hazardous materials (HAZMAT) User's Guide. (OPNAV P-45-110-91, June 1991) which gives control measures, safety precautions, health hazards, spill control and disposal guidelines for 20 hazardous material groups.

POC for all PMS and Related Manuals: Jim Nelms

Phone Number: (757) 485-6112

Fax Number: (757) 485-6261

Address: Commanding Officer, FTSC Atlantic, ATTN: Code 4103, 9727 Avionics Loop, BLDG 203, Norfolk, VA 23511-2124

INTERNET Address: jim_nelms@imail.ftsclant.navy.mil

6.5 Marine Gas Turbine Inspectors Handbook for the SSGTG

The inspectors Handbook is not intended for normal ships force responsibility but does provide an idea of the scope in detail and man-hours of various requirements for inspecting the Gas Turbine Generators. This manual (S9234-AD-MMO-050/LM2500 ACN 2/A) consists of chapters on general information, heavy repair, general cleaning, and general inspection.

The inspector periodically performs piston liquid fuel valve checkout and alignment for the 501-k17 & 34 GTGs, conducts a review of the marine gas turbine logs, physically inventories technical directives, physically verifies that technical manuals are current and in usable condition, and performs engine start evaluations. Visual inspections are conducted on the module, generator lube oil flow, head tank, intakes, inlet plenum, compressor, accessory gearbox, diffuser case, combustor, turbine, and reduction gear enclosure. A borescope of the engine is also performed. Any automation effort should include a review of the system's inspection requirements.

The focus of this chapter was to give the reader an idea of the resources that should be analyzed while designing, and certainly before implementing a new naval shipboard system that will change the way the crew interacts with their machinery.

The EOSS must be revised to describe the proper operation of the equipment under all the various conditions once the Health Monitoring System or RSVP machinery monitoring is installed aboard ship. The Technical Manual would also require revision since it is also used for operation of the GTGs in conjunction with the EOSS.

6.6 Scenarios

In defining the information requirements the thesis combines information from the system expert interviews, the operating manuals, and the maintenance manuals. The EOSS and technical manual provide the most detail in the steps required to perform tasks during routine, casualty, and maintenance evolutions. They also make reference to each other during procedures. Note that tasks are both physical and cognitive.

The following scenarios were developed on an overall ship basis or top level scenario to investigate how RSVP might change the manner in which the crew

operates the ship. Table 3 to 8 compare how the DDG 51 performs the task and how the next generation Destroyer DD-21 with RSVP installed performs the task.

Ship wide events, maintenance evolutions, routine engineering processes, and an engineering casualty are modeled. Subsequent to this top-level picture, the scenarios begin to focus in on the Gas Turbine Generators and specifically to the operators directly responsible for them. An illustrative case of the gas turbine generator startup procedure was chosen as a routine evolution. The Casualty scenario is developed from a casualty response procedure for the Electric Plant Control Console (EPCC) operator in response to the low lube oil pressure alarm on the Gas Turbine Generator. Many other casualties can be modeled such as a class Bravo fire in the Gas Turbine Generator module, overspeeding of the Gas Turbine Generator, or unusual noise or vibration of the GTG. The representative maintenance scenario is the water washing of the GTG's.

The following scenarios have been developed and are shown in Tables 3 to 9.

- Routine Watchstanding
- Machinery maintenance
- SSGTG Startup
- SSGTG Low Lube Oil Pressure Casualty
- Steaming in heavy seas
- Missile hit above the waterline
- Maintenance System

Table 3 Routine Watchstanding

Time	Event	Machinery DDG-51	DD-21 with RSVP
T0	Watch turnover. Oncoming operator should check all spaces, machinery and status boards.	1. Oncoming Watch takes a complete tour of the machinery spaces, looking at all equipment, bilges etc. 2. Reviews all paper logs, tagout records, work procedures and status boards. 30 minutes	1.Oncoming Watch takes a cursory tour of the unmanned machinery spaces. 2. Review all situational awareness summary displays, and data trends. 10 minutes
T1	Hourly data logging	Operator walks around each component to physically view the meters and record the reading in ink on a logsheet. 20-30 minutes	RSVP operator checks automated data logs and trend displays. 2-3 minutes
T2	Health of Generator of #2 SSGTG approaches alarm setpoint.	Only way to notice is by looking at the local meter.	Temperature rise noticed on graphical presentation. RSVP operator checks automated data logs. Begins system checks.
T3	A spurious misalignment of the cooling water system has caused the Generator to begin to overheat.	Summary Temperature alarms for Generator come on.	RSVP operator diagnoses the problem by reviewing: ➢ SW System configuration status and situation awareness display ➢ Component health display ➢ Temperature trends.

Time	Event	Machinery DDG-51	DD-21 with RSVP
T4	High Temp Alarm on #2 Generator air cooler	Operator reads summary alarm panel, just now aware of a problem.	RSVP system has informed him that SW cooling is inadequate and recommended reducing load until flow is restored. Alarm is avoided. Diagnosis in several minutes
T5	Temperature of Generator continues to rise.	Operator sends a man to investigate cause, meanwhile must trip the GTG and startup the standby GTG.	Affected GTG is unloaded, the other is carrying the load. Send operator to restore flow (or automatically with motor operated valves)
T6	Problem diagnosed and cooling water system realigned	Slowly cooling down the affected generator. Diagnosis 10-20 minutes	Flow restored. RSVP operator monitors alignments, components, and device cooldown. Electric plant in a full power lineup.

Table 4 Machinery Maintenance

Time	Event	Machinery DDG-51	DD-21 with RSVP
T0	Peacetime steaming (Condition 3)	Normal roving watchstander tours the spaces looking at equipment and gauges.	Continuous system assessment and anomaly detection
T1	First measurable indication of bearing problem	No problems noted	Adjust data points collected & collection frequency
T2	Bearing fault continues to evolve	No problems noted	Lower level diagnostics run, feature extraction, trend analysis displayed.

Time	Event	Machinery DDG-51	DD-21 with RSVP
T3	Bearing fault identified	No problems noted	Bearing fault identified, confidence level computed Operator at watchstation notified of condition & confidence level
T4	Bearing fault/failure data varies	No problems noted	Prognostic algorithms develop failure prediction
T5	Bearing condition exceeds acceptable limits for mission profile	Problem detected by log reading, supposed bearing problem	Recommendation is made for repairs. Load shedding, alternate GTG operation options presented
T6	Repair parts order, repair resources identified	Ships crew attempt to diagnose problem	Alternate GTG brought on line, GTG w/ bearing problem taken off line, backup status until parts arrive
T7	Parts arrive –Repair conducted	Bearing failure progresses rapidly GTG out of service until cause is found and corrected, and repair can be performed	Bearing repair completed in advance of failure GTG down time minimal

Table 5 SSGTG Startup

Step	Event	Machinery DDG-51	DD-21 with RSVP
1	Set the valves on the ship to the positions necessary for SSGTG startup and operation.	Currently requires a hand over hand verification of the system lineup. Valve lineups are manpower intensive especially when they are written on a per system basis rather than a per compartment basis.	The Console operator can verify all remotely operated or monitored valve positions. The manually operated valve positions may be verified by valve lineup paperwork or by sending a man to the spaces.

Step	Event	Machinery DDG-51	DD-21 with RSVP
2	Perform all procedures of the EOSS required for startup.	The GTG tech manual refers the operator to the EOSS procedure.	The EOSS is summarized on the screen and lists and tracks the steps to completion.
3	verify System alignment	Same as step 1	Same as step 1
4	Verify that online and on coming GTG are in remote control. Monitor speed, inlet temperature, and vibration of the GTG to be started also monitor GTG lube oil pressure during startup.	Currently all machine parameters are not available remotely. An operator is still required to walk around the machine and take hand written readings on a Logsheet. The Logsheet is then reviewed by the EOOW for verification	All controls switch positions can be verified on the screen display, as well as all operating parameters.
5	Ensure the online and oncoming Generators are in normal governor mode, normal voltage regulate mode and automatic mode.	All remote controls switch selections can be verified on the EPCC display, however any remote switches still require verification by an operator in the space.	All controls switch selections can be verified on the screen display.
6	Select Generator air starting mode (either high pressure or low pressure air.) Momentarily depress the START button for the on coming Generator. Verify GTG Generator run light is lit within 30-45 seconds. Again monitor GTG parameters	All remote controls switch selections can be verified on the EPCC display, however any remote switches still require verification by an operator in the space. Currently all machine parameters are not available remotely. An operator is still required to walk around the machine and taking hand written readings on a Logsheet. The Logsheet is then reviewed by the EOOW for verification	All controls switch selections can be operated and verified on the screen display, as well as all operating parameters.
7	adjust frequency to 60 Hz using Generator frequency lower/raise switch. Adjust voltage to 450 volts using Generator voltage lower/raise switch. Report to EOOW No. 1 GTG started.	Frequency and voltage control of the GTG's is done from the EPCC display.	Frequency and voltage control of the GTG's is done from the display screen. Communications can be verbal or the EOOW status screen will provide the same information.

Step	Event	Machinery DDG-51	DD-21 with RSVP
8	Verify that 14th stage bleed air valve is in remote at No. 1 GTG LOCOP.	All remote controls switch selections can be verified on the EPCC display, however any remote switches still require verification by an operator in the space.	Again all electronics switches and valves positions will be available on the screen display, and can be controlled from the HCI screen if desired.

Table 6 SSGTG Low Lube Oil Pressure Casualty

Step	Event	Machinery DDG-51	DD-21 with RSVP
1	Lube Oil low press alarm sounds/indicator light illuminates.	Operator must go to the machine to monitor lube oil meters to determine if the alarm is on the turbine or the Generator. Report to EOOW lube oil pressure low on No. 1 GTG Turbine/Generator. Oil pressure by lube oil meter is X psi.	All operating parameters can be verified on the screen display. Communications can be verbal or the EOOW status screen will provide the same information.
2	Actions that occur with the GTG in auto standby and the EPCC in auto mode.	With the GTG in auto standby and the EPCC in auto mode this alarm will initiate a HP start of the standby GTG. The Turbine over speed protection system (TOPS) will react faster and automatically open the affected GTG circuit breaker. The opening of an online generator breaker will also cause a HP start of the standby GTG and automatically parallel it with the remaining online GTG.	The next generation health monitoring and control system Diagnostics would automatically start the standby Generator parallel it and place it online followed by securing the affected GTG.

Step	Event	Machinery DDG-51	DD-21 with RSVP
3	the EPCC operator must 1. Stop the affected Gas Turbine Generator. 1. Ensure the affected Generator breaker opens. 3. Ensure the standby GTG starts and parallels with online GTG. 4. Place mode selector switch to manual permissive.	1. Stop the affected Gas Turbine Generator by pushing the shutdown button. 2. Breaker position verified visually on the EPCC. 3. Most indications of a GTG start and parallel are available on the EPCC. However some parameters must be checked locally. 4. Currently operable From the EPCC.	1. Stop the affected Gas Turbine Generator, if the system has not already done so automatically. 2.,3.,4. The next generation health monitoring and control system would display all of these parameters on the touch screen and the Diagnostics of the system would automatically start the standby Generator parallel it and place it online followed by securing the affected GTG and placing the switches to the required positions.
4	Monitor the unaffected GTG's. Monitor the affected GTG for post Shutdown fire.	Although some remote temperature readings would indicate the post Shutdown fire, procedure requires that a man observe the engine locally.	All operating parameters can be verified on the screen display. Expect policy change so man at the engine is not mandatory.
5	Report to EOOW No. 1 GTG stopped No. 2 GTG started and in parallel with number three GTG	Communications are face to face or via sound powered phone circuits.	Communications can be verbal or the EOOW status screen will provide the same information, and configuration changes give an automatic all station alert or report.
6	when ordered reset the TOPS.	Accomplished by pushing the TOPS reset button.	Expect the reset would be automatic, once conditions are satisfied.
7	Troubleshooting the problem.	Manually diagnose problem using Tech. Manual and other resources. Repair any failed machine components.	Fault identified, and confidence level computed. Operator at watchstation notified of condition & recommended repairs.
8	GTG restoration following the casualty.	Once the problem has been found and corrected, when ordered press the configuration change reset button and place the operational mode selector switch back in the auto position for the affected machine.	All operating parameters can be verified on the screen display, to ensure equipment is satisfactory. Then the OP. MODE SWITCH can go to auto.

Table 7. Steaming in Heavy Seas

Time	Event	Machinery DDG-51	DD-21 with RSVP
T0	Steaming in heavy seas (Sea State between 6 and 7) (Condition 3)	Propulsion & electric plants in normal steaming lineup	Propulsion & electric plants in normal steaming lineup
T1	Heavy seas cause main breakers to trip off line	High fluctuation in line current causes GTG to load shed/ trip off line, sometimes causing the unfaulted GTG to trip by TOPS resulting in a "dark ship".	Automatically detect electrical load fluctuations and reconfigure GTGs to share load, no "dark ship".
T2	Post-event operations	Manually diagnose & repair failed machine	Diagnosis performed automatically, operator gets recommended course of action

Table 8. Missile Hit

Time	Event	Machinery DDG-51	DD-21 with RSVP
T-1	General Quarters	N/A	Machinery configured based on identification of incoming threat
T0	Missile hit, 3rd deck, damage to 2nd deck Class A & B fires	No machines in affected spaces Loss of electrical power in affected spaces	No machines in affected spaces Loss of electrical power in affected spaces
T1	Damage assessment	Nearby personnel evaluate machinery, manually bring systems back on line	HMS provides continuous status condition of GTG during and after damage event Operator at watchstation informed of which machines had shock rating exceeded System elements tripped off line by shock automatically rebooted and reporting updated status
T2	Set fire, smoke, & damage boundaries	Emergency lighting provided automatically	Emergency lighting provided automatically
T3	Extinguish fire	N/A	N/A
T4	Prevent fire in adjacent spaces	Manually restore electric power to affected spaces based on manual inspection	Operator at watchstation controls restoration of electric power to affected spaces based on inputs from HMS

Table 9 Maintenance System

Step	Event	Machinery DDG-51	DD-21 with RSVP
1	A maintenance item is scheduled to be performed.	PMS schedule requires item to be performed based on a chosen periodicity, without regard to the actual condition of the item. Note that the paper work can be ten times the man-hours of the actual performance of the item.	System condition is continuously monitored and analyzed. Maintenance item is triggered by a diagnostic conclusion of a need to do the item based on the component's condition. This CBM philosophy reduces unnecessary maintenance

Example: Maintenance items requiring a GSM3 about 2.4 hours and an apprentice 2.1 hours to assist. These items are accomplished every 1500 hours of operation.

a. Replace turbine low-pressure single and dual fuel filter elements.
b. Clean and inspect high-pressure fuel filter element.
c. Replace turbine lube oil filter element.
d. Replace reduction gear lube oil filter element.
e. Replace generator lube oil filter element.
f. Return to readiness condition and leak check.

The CBM approach would be "when necessary", perform appropriate maintenance requirement as follows:

a. Replace turbine low-pressure fuel filter elements when differential pressure across single element filter exceeds 5 psi and/or dual element filter differential pressure exceeds 7.5 psi.

b. Replace turbine lube oil filter element when turbine lube oil is replaced.

c. Replace reduction gear lube oil filter element when differential pressure across filter exceeds 7 psi or when turbine lube oil is replaced.

d. Replace generator lube oil filter element when differential pressure across filter exceeds 5 psi or when generator oil is replaced.

Now that the detailed scenarios have been developed they provide a good picture of the tasks required of the operator to maintain and operate the Ship Service Gas Turbine Generators. To supplement this information, interviews of system experts, operators and instructors is required to better understand how the gas turbine generators are currently monitored and maintained, and any information that these experts require to perform their duties. The next chapter describes the development of the survey.

Chapter 7 Survey and Interview Development

An interview and questionnaire was developed with human cognitive engineering methods in mind. The questionnaire goal was to determine user information requirements for monitoring and control of the Allison 501 K17 & 34 GTGs. The original interview must be reviewed to ensure that the author's opinions are not leading the questioning. Several versions of related questions were used to assess the participant's true answers to the question being asked.

7.1 Purpose of Interviews

The purpose of the interviews of system experts operators and instructors is to better understand how the gas turbine generators are currently monitored and maintained and the information that these experts require to perform watch standing aboard ship as well as maintenance and testing both at sea and ashore. The proper design of this system requires an in-depth knowledge and understanding of the tasks that are to be supported and the environment and context in which those tasks are to be performed. The shipboard operator's experience and understanding of the environment, in which the system is to be used, must be included in the early design stage. The answers to the questions are used in determining how sensor data will be analyzed and displayed, how much data should be logged, how much assistance and control the interface should provide, and what levels of information access should be provided for the various tasks.

7.2 Context of Interviews

The questionnaire was set in the context of an at-sea, on watch scenario. The watch progresses from routine evolutions to abnormal conditions and finally casualty conditions. The goal is to determine what information and diagnostics would be most useful as an operator aide to help the watch stander make the right determinations and

take the proper actions during the watch.

7.3 Disclosure of Information

Part of the questionnaire approval process is to include disclosure to and get approval from those who will participate. The following statement was added to the Participant Consent Form. "We will audiotape your interview so that later we can review the information you have provided. The audiotape is for our evaluation of the system; it will only be used for development team review and internal use. The data you generate during this study, and the audiotape used to record your interview, will be kept strictly confidential. The information you provide will have your name removed and only a number will identify you during analyses and any written reports of the research."

Although some of the designers requested videotaping of the interviews, this was deemed unnecessary. Videotaped interviews provide further insight into the user's opinions, especially when the observation occurs at a prototype of the system, since a prototype was not available, no video was taped.

7.4 Demographics of Participants

The participants were:

- 3 SSGTG In Service Engineers-(civilian design engineers at NAVSES Philadelphia)
- CO and Chief Engineer of the USS Ticonderoga (CG-47)
- Chief Engineers of the DDG-78 and an LPD
- Engineering Dept. LCPO of the DDG-80
- 2 DDG-80 CPO US Navy Engineering plant Fleet SSGTG Operators
- 2 DDG-80 Enlisted US Navy Engineering plant Fleet SSGTG Operators
- 5 CPO US Navy Engineering plant and Electronic Controls SSGTG Instructors

Table 10 Participant Demographics Regarding Gas Turbine Generator Experience

Background on the 20 Participants	Scaling Factor	Mean	Std. Dev.	Min.	Max.
Rank or Job Level	E1-E9 +1 for each officer or government rank	9	3.1	6	15
Years Experience	In Years	15	4.6	7	25
Education Level	12=High School, + 1 for each year of college	14	2.2	12	18
Years ICAS Experience	In Years	2.8	2.8	0.2	10
ICAS Comfort Level	1=very uncomfortable, 7= very comfortable	5	1.8	1	7
Years ECSE Experience	In Years	2.6	3.2	0.5	9
ECSE Comfort Level	1=very uncomfortable, 7= very comfortable	3.9	2.2	1	7

7.5 Interview Process

A thirty minute presentation consisting of a brief on the topic of this thesis, the author's goals, the importance of their input, and a storyboard illustrating how the system could enable highly automated, minimally manned warships in the future was given to provide context and focus for the interviews. Twenty volunteers participated in the interview and questionnaire, nine of which were audiotaped.

The plan was to conduct a questionnaire sampling of a large audience, and then conduct taped interviews with a sample audience from several of the categories shown above from the demographic profile. Each person brings a unique perspective on the problem that can contribute to achieving a well-designed system that can be integrated easily into the environment for which it is intended. The audiotapes and questionnaires will help designers to gain a better understanding of the ship environment, and crew activities as they relate to RSVP.

A presentation of the objectives of the thesis, the proposed HMS system from the RSVP ATD, and several slides on the possible user interface were used to illustrate the context for the people who would be participating in interviews or questionnaires.

7.6 Development of Questionnaire

A draft questionnaire was prepared and then refined through several reviews by industry experts in human factors and system integration. Suggestions were that the author must not inject too much opinion into the questions so as to lead the answers, and the questions should be made less specific to allow more free thought in the answers. In contrast the participants who know the system very well, felt that the questions were not specific enough.

A series of tools were generated by Honeywell Technology Center, Inc. to help their European colleagues integrate Human Factors techniques into their software development process. The tools were written for non-Human-Factors experts and were used as a guide for the thesis interview preparations and knowledge acquisition tasks. The Honeywell document is a general overview that describes tools and procedures for collecting information from product users and presents three data collection techniques; questionnaires, interviews, and observations. The final questionnaire that was used is included as Appendix B.

Chapter 8 Summary of Information and Sensor Requirements

This Chapter summarizes results from the interviews, surveys, and task descriptions. Survey results are presented in their entirety in Appendix C. The analyses were based on detailed reviews of ship board operating manuals and a series of interviews with subject matter experts ranging from deck plate operator to system design engineer. The sources were combined to develop a template for the information required such as what sensors are most important what information needs to be presented and how often.

A large volume and variety of responses were received during the interview process, so only the most common and important responses are described in the following paragraphs.

8.1 Watchstanding and Operation of the SSGTG

In general watchstanding, the most important elements for success and productivity are clear and concise communications, well planned agenda, properly trained watch team, and no time pressure.

With regard to starting the SSGTG most operators requested an automatic sequencing system to startup the Generator automatically including verification of prestart requirements and prompting the operator when a requirement was not met. Additionally a graph of startup parameters versus time at the HCI was deemed valuable to describe the engine's performance compared to the same profile over previous start-ups.

During steady state operations the most important ideas were to display all critical parameters graphically, and to redesign the alarm system so that only pertinent parameters will have alarms and concise readings are to be displayed with the alarm. Auto configuration change buttons that would do all the steps associated with load shifting, paralleling, and balancing load on the SSGTGs were consistently requesteded.

For shutting down the SSGTG, the respondents asked for automatic shutdown and cooldown sequencing, as well as automatic shutdown checks.

During a casualty, an auto recovery system, which prevents the loss of both GTGs is desired. Smart operator aids to help diagnose casualties are also needed.

8.2 Smart Operator Aids

The following operator aids for assistance during casualties are ranked based on participant's responses.

1. The system prioritizes the most critical problem to help maintain operations.
2. The system takes action after your approval.
3. The system lists impacts on the plant equipment.
4. The system takes action automatically, without your approval.

Operator aids to help with navigating through the procedures were ranked by their relative importance. (1 being the most important)

1. The system identifies the procedural steps to be taken.
2. The system lists an outline of the required steps. The system tells you the correct order for your actions.
3. The system displays the actual procedure.
4. The system keeps track of steps as they are completed.

Other: The system warns of missed steps. The system lists equipment needed to do repairs.

The following operator aids for screen display during a casualty are ranked based on participant's responses.

1. The screen shows Current Fault conditions.

2. The screen shows Current Priorities.

3. The screen shows Status of Actions.

4. The screen shows General System status.

Other: console configurations should be standardized so the display will always be familiar to all watchstanders. Therefore there will be no confusion in the heat of battle.

8.3 Sensor Requirements

The top 5 "Must Have Displayed" Sensors were:

- Turbine Inlet Temperature (prefer each cylinder)
- Lube Oil Pressures and Temperatures
- Speed (either RPM or frequency)
- Vibration monitoring
- Generator: Voltage, current, kW

The list remains essentially constant whether operating normally or during a casualty. A common request was for additional remote sensors currently not available on the remote consoles. They are:

- Fuel Oil manifold pressure.
- Individual turbine inlet temperatures.
- New tank level indications for all equipment.

- Starting air indications.
- Oil Quality Monitoring.

The rest of the following items were mentioned by at least one respondent. Fuel control valve position, current fault relays, filter differential pressures, sea water cooling systems, air flow, system diagrams, heat sensors, video cameras, fuel oil consumption, fire alarms, and flooding alarms.

Since the most difficult problems to diagnose were often circuit cards or electronics and cable problems, some fault indicating sensors are also desirable in these problem areas.

Note that the "Least Trusted Sensor Readings" were Tank Level Indicators (TLI), vibration sensors (out of cal or picking up interference), Fire and Flooding Alarms (due to frequent false alarms) and manual and out of cal gauges. The following suggestions and comments about the sensors were offered.

1. Performance of TLIs in a hostile environment decays very quickly especially Fuel Tanks at the oil/water interface.

2. To correct TLIs and bilge alarms build in time delays, which automatically adjust for various sea states.

3. Watchstanders must trust their indications.

4. All sensors must be operating within acceptable accuracy limits and have valid calibration.

5. Cameras can provide a Virtual Presence but still cannot "see" from all angles.

Other sensors not mentioned in the survey will be required by sound engineering practice. These can be decided jointly by the manufacturer and the customer. The Auxiliary Gear Box (AGB), the Reduction Gear Box (RGB) and the generator foundation and shell should all have vibration monitoring.

8.4 Control Functions

With regard to control, the majority of respondents did not want fully automatic control of the machinery, but preferred that the system determines the most likely problem and provides recommendations. The system could also take an action after the operator's approval.

A majority of respondents were in favor of having open access to the information, except that some felt only the engineering department should have access. With respect to restricting access to control functions, a majority favored a login and password system. Some favored simply relying on the ship's qualification program that would grant access once an individual had qualified for that position. There is no need for a master and slave console arrangement, the levels of access will be different for the different levels of the chain of command.

The most important control functions to have are the starting and stopping of machinery, electrical power control and electric plant configuration changes, valve operations, valve lineup operations, safety critical items, and manual operation backups for all critical functions.

Once a problem is diagnosed, most operators wanted some form of the applicable procedure displayed on the screen. In general automatic response was only desired for the most serious casualties.

8.5 Data Updating

With regard to how fast data should be updated. The responses were varied as follows.

1. A time stamp is essential to sort out the sequence of events

2. Near real time.

3. Data continuously displayed and updated.

4. Following data rates had equal number of votes:

Once per second, twice per second for most critical parameters, or four times per second.

5. The much faster update rate of 200 milliseconds or five times per second is better for time stamping data, even as fast as ten times per second is good for time stamp data. Although updates in the milliseconds will unnecessarily burden the data storage and traffic architecture. Perhaps updating on an as requested basis only is best.

The following general comments about update rates were also mentioned.

1. When displayed meters are updated too frequently they flicker and distract the operator causing eye fatigue.

2. To correct flickering, design in dead bands to prevent hunting of the meter.

3. Decimal accuracy is not necessary; use standard gauge accuracy.

8.6 Attributes of an Alarm

The proper design and use of alarms and warnings was described in the following:

An alert should give a clear concise description of the exact component and its problem and should tell the set point and current reading

System Should give an accurate parameter reading with exact reading displayed and updated.

System should give a history of the alarm parameter and give correlations to other related parameters.

Console should recommend possible actions along with the alarm.

The system should give symptoms of various problems related to the alarm.

The remaining responses received at least one mention. Display the value that is at the set point. Eliminate Summary Alarms. Provide the scrolling display with time stamp on Alarms. Show the parameter's rate of change and give time to failure. Avoid too many warnings, which may confuse the operator. Give warnings when alarm is faulty.

8.7 Presentation and Archiving Data

The most useful presentation of information in order of most common response was graphical presentation, numerical values with the option to graph over an operator specified interval, log-taking format, charts versus time, bar graph trend analysis, pictures of spaces and components, rates of change, data with alarm trip points, and audible presentation along with the visual data.

At least 24 hours worth of data history is desirable, with the ability to go back farther in time and decide. Less common responses were a week's worth, up to 48 hours worth, 30 days worth of logs available, or have all data since last sensor or system maintenance.

The rest of these ideas were mentioned. The amount of history is component dependant. There should be 15 minutes worth displayed on screen, and keep 20 to 30 minutes in an active buffer. There should be continuous daily downloading to an archive system. Data should be stored by the megabyte, and downloaded when buffer is full. Maintain a real-time display only, no logging requirements. Maintain up to four hours worth. Maintain as much as the system can handle. Copy to CDs periodically to download the data buffer.

8.8 Task Automation/Elimination Choices

Functions that were not desired to be automated were engine shutdowns, which should not be automatic but always by operator's choice. No automatic function should cause a loss of electrical power to both sides of the ship. Any overboard discharge or environmental concern should not be automated. Motoring of the GTG's is already an abnormal situation and should not be automated. All automatic functions must have the ability for operator intervention.

The following functions or daily requirement can be eliminated or automated.

1. No more paper logs taking.
2. No more oil sampling.
3. Delete daily sump and tank checks.
4. Routine PMS.

8.9 Maintenance

These maintenance aids were ranked by relative importance, results are:

1. To display recommended repairs.
2. To display a prediction of remaining component life.
3. To automatically do a stock check for parts.
4. To be linked to an Automated Parts List (APL) for ordering parts.
5. Automatic Scheduling of Maintenance.
6. To be linked to automatically maintain equipment history.

Other Ideas: system should provide a daily burst of information via the Internet and satellites

to the Intermediate Maintenance Activity or other ships for information and recommendations. Maintenance Functions that should be moved off of the Ship to the shore are:

1. As much maintenance as possible to be moved ashore with the exception of on watch equipment PMS to maintain the machine's health.
2. Maintain emergency repair maintenance on board.
3. Remove or eliminate routine PMS.
4. Remove or eliminate routine repairs or have a quick change out parts system on board.
5. Move internal inspections ashore.
6. These remaining comments were those mentioned at least once:

   Move scheduling of maintenance ashore.

   Move parts ordering ashore.

   Move shipboard cleaning ashore.

   Move calibration of gauges ashore.

   Move record keeping on machinery ashore.

A summary of the answers was presented, however the manufacturer must be consulted to verify and compare what sensors are already installed, and what sensors if any have been overlooked. All of the results are presented in Appendix C.

The next chapter makes estimates to try to predict how many man-hours are saved, and then calculates how many crewmembers could be removed due to man-hour reduction.

Chapter 9 Functional Allocation and Crew Reduction Estimates

This chapter presents the functional allocation of manpower and automation. Manning considerations are presented, an approach to estimating how many man-hours can be saved with the RSVP machinery HMS is presented, as well as the presentation of workload and engineering watchstations required.

9.1 Manning

The legal limits on commercial ship manning are derived from the Safety of Life at Sea (SOLAS) rules and are ratified by the International Maritime Organization (IMO). As a benchmark the minimum commercial ship manning approved by the USCG today is 13. Recently the requirement for a radio operator was eliminated due to the accuracy of GPS and advancements in electronic navigation and communication. A cook or "steward" is still included on most crews, although not required. [22]

The 13-man crew breaks down as follows:

1 Master
3 Licensed Mates
3 Unlicensed Apprentice Boatswains
3 Licensed Engineers
3 Maintenance Department Personnel
Total=13

US Navy Warships are certified by the US Navy and are not required to meet specific SOLAS or USCG rules. The warships must meet the rules of the road to operate with sufficient means available to safely navigate the vessel. The destroyer design with RSVP technology must verify that all functions required to safely operate the vessel and carry out the intended mission are allocated to either a human or technology such as remote sensors and video cameras.

This manning is based on supporting a three-section rotation for normal steaming periods, while in times of increased vigilance the crew would go to a two-section

rotation. The crewmen must be cross-trained sufficiently so that they can perform a wide variety of tasks underway. This requires a doctrine change within the navy's historically specialized enlisted rating scheme. The crewmembers of the automated destroyer must have varied skills and be well trained in the use of computers and information technology.

The concept of operations is of an unmanned engine room and automated damage control systems. The crewmen use the RSVP system and camera displays to maintain situational awareness. The GSM and GSE would monitor and control the main propulsion, electrical, and auxiliary machinery. Both the GSM and GSE would make periodic tours of the ship to provide backup to the sensors and cameras, and provide the fire and security checks that are standard warship practice. The concept also assumes that all maintenance except for the minimum required to keep the equipment running such as filter replacements and lubrication has been moved to the shore infrastructure. In the event of a major component failure, the systems have redundancy and only minor corrective maintenance would be performed if the schedule permits.

The DDG-51 Class Ship Manpower Document [ref] requires the following Engineering Department Manning:

Officers: CHENG, MPA, DCA, AUX, ELEC	5
Main Propulsion GSE/GSM Rates	30
Electricians	5
Others: Auxiliarymen, Repairmen, HT,etc.	28
Total	68

An estimate of manpower affected would be all except the "others" category, thus a manpower savings factor can be applied to the published weekly required manhours for the 40 affected crewmen. A report by Carlow International Inc. [2] documents the results of an effort to estimate the extent of human work reduction that may be realized by provision of the RSVP system to existing ship work requirements. The analysis was performed for the DDG51 workload of engineering control personnel. Previous analyses of workload associated with the existing designs were reviewed and work load redistributed according to the functionality of RSVP and its ability to perform extensive ship monitoring, data analysis and fusion.

Results of the study estimate workload reductions of 47% for personnel tasks performed in the machinery spaces aboard DDG-51 for each four-hour watch under condition III steaming. Applying this 47% reduction factor to the DDG-51 ship manning document [23] can give an estimate of feasible crew reductions.

Table 11 Weekly Man-hours Without and With RSVP Technology

Engineering Department	**Required wout/RSVP**	**Required w/RSVP**
Own Unit Support(Ous)	42	22.3
Productivity Allowance(Pa)	8.4	4.5
Service Diversion Allowance(SD)	7	3.7
Training(T)	7	3.7
Department Support Total	64.4	34.1
E Division		
Planned Maintenance(PM)	91.6	48.5
Corrective Maintenance(Cm)	76.8	40.7
Own Unit Support(Ous)	88	46.6
Facilities Maintenance(Fm)	16.8	8.9
Productivity Allowance(Pa)	36.3	19.2
Service Diversion Allowance(SD)	35	18.6
Training(T)	35	18.6
E Division Total	379.6	201.2
MP Division		
Operational Manning(Om)	1008	534.2
Planned Maintenance(PM)	424.3	224.9
Corrective Maintenance(Cm)	164.7	87.3
Own Unit Support(Ous)	133	70.5

Facilities Maintenance(Fm)	143.7	76.2
Productivity Allowance(Pa)	88.3	46.8
Service Diversion Allowance(SD)	210	111.3
Training(T)	210	111.3
MP Division Total	2382	1262.5
Total Affected Man-hours	**2826**	**1497.8**
Saved ManHours		**1328.2**

ONR estimates that a reduction of 34 men can be accomplished when all of the elements of RSVP are in place. The engineering department estimates are shown below.

On 10 hr Workday	On 8 hr Workday
19 Men Removed	**27 Men Removed**

9.2 Human Systems Integration Approach

Human Systems Integration (HSI) methods applied to modeling and analysis of watchstander workload of Engineering Control personnel aboard current DDG 51 ships, were used to define the current baseline tasks and workload. Similar models were developed for workload under alternative concepts for increased intelligent sensing and centralized display of propulsion and auxiliary machinery [2].

The following are the general Engineering Control manned stations, manned spaces and personnel assignments for all readiness conditions [2]:

- After Steering Helmsman
- Aux. Machinery Rm. 1 Supervisor
- Aux. System Monitor
- Electrical Plant Cont. Console Operator
- Electrical Repairman
- Electrical Switch Board Operator (two)

- Engineering Officer
- Engineering Officer of the Watch
- Equipment Monitor
- Machinery Repairman
- Oil King
- Engine room operator (several)
- Propulsion and Aux. Control Console Operator
- Propulsion System Monitor
- Shaft Cont. Unit 1 and 2 Operator (2 operators)
- SS Gas Turbine Gen. Operator (two)
- Talkers (several)

Manning under Condition I, Condition III, and special evolutions can require up to 23 persons to man up Engineering. The workload analyses being conducted in the machinery monitoring and control area addressed Condition III (wartime steaming). Under Condition III, the following stations are manned:

Central Control Station

- Engineering Officer of the Watch (EOOW)
- Propulsion and Auxiliary Control Console Operator (PACCO)
- Electric Plant Control Console Operator (EPCC Op)

Engineering Spaces

- Engine Room Operator 1 (ERO 1)
- Engine Room Operator 2 (ERO 2)
- Propulsion Systems Monitor (PSM)
- Auxiliary Systems Monitor (ASM)
- Oil King

These stations represent those for which the 47% workload reduction estimation were generated, provided RSVP is installed [2]. This chapter presented another facet of results in that shipboard manning can be reduced. The estimates of this chapter are used to determine the virtues of a capital investment and the cost vs. benefits of this project aboard ship, in chapter 10.

Chapter 10 Capital Investment Analysis

This chapter considers the financial aspects of implementing the automation technology aboard ships. The costs of the technology are weighed against the benefits of reduced manning and condition-based maintenance and the resultant savings in manpower and maintenance costs.

10.1 Market and Financial Vision for Sensors

The vision for the new "smart sensors" is that in the future all machinery shall have these sensors embedded during production at the original equipment manufacturer (OEM). The development of these sensors must be commercially driven or else development time and cost will be excessive. As it stands today the sensors must be installed on the machinery after purchase or as a backfit to be installed on machinery already aboard ship.

Sensors are available to monitor temperature, pressure, vibration, chemical content, corrosion detection, oil quality (although still in the research phase) and many other parameters. Today's sensors are smaller and less expensive to produce for example old vibration sensors cost about $100.00 each but today they are the size of a pencil eraser and cost about $10 each.

The commercial potential is significant, when considering that sensors are needed for CBM, emissions reduction, and noise control and monitoring of many different machines. According to US census data, every year 320 million motors, generators, pumps, and gearboxes are produced. These machines require some 870 million bearings. If the OEMs implement smart sensors into the production line, then the effort and cost of implementing a machinery monitoring and control system will be much easier and less expensive.

10.2 Commercial Shipowner Perspective Capital Investment Analysis

The goal behind the microeconomic decisions of shipowners involves striving to optimize their operations and thus maximize profit. Since profit equals revenue minus cost, this technology can help reduce costs and as such supports greater profit.

This technology is in effect the product "substitute" for crewmembers (man-hours). In theory, all shipowners who are not yet operating with the minimum allowable crew will be interested in reducing operation and support costs with this technology.

There are externalities, both positive and negative, related to the economic success of this investment. On the positive side, small technology companies and their suppliers will have growing revenues and should prosper. Furthermore the price of labor may be reduced in an attempt to compete with this new technology. On the downside those personnel whose jobs have been eliminated, and the seafarers unions, will clearly see this as a negative business venture.

In the short-term there will be acquisition, installation, and training costs but in a short time (or payback period) the benefits in manpower and maintenance will outweigh the costs, the net effect being a large monetary saving over the lifecycle of the vessel. The estimates assume that the vessel's operating profile remains constant throughout its life, and implies that newer highly automated ships with smaller crews and CBM systems will have lower O&S costs. With upgrading, currently operating vessels can achieve the same lower O&S costs.

There is a limit to the savings per sensor or per machine, so, the approach is to automate the machines that are the most manpower intensive and have the most costly maintenance first to most effectively reduce crew size and maintenance costs.

Figure 14 shows the cost of automation and manning [15]. Varying crew size is shown along the horizontal axis; cost to meet the mission is shown on the vertical axis.

The total cost line is made up of two components: automation technology and crew manning. The chart is a traditional systems optimization chart, and although it is applicable to a single ship, it is more meaningful when applied to a fleet.

The cost of current ships consists predominantly of crew costs, with a small cost of automation. As crew size is reduced, ship operating costs fall, and the cost of automating their functions rises. The cost rise is not linear; it rises more steeply as crew size is further reduced, so there is an ideal balance between human systems and automation. Figure 14 shows an optimum financial point, which should be the goal toward which new ships and systems are designed.

The cost of automation is predominantly invested in software. This is generally a nonrecurring cost, but there will be a software-maintenance burden. Because many software objects will be common across many ship platforms, as more ships use the autonomic software, the real cost per ship of the automation technology will fall. This means that the optimal point eventually will drift over to the left. [15]

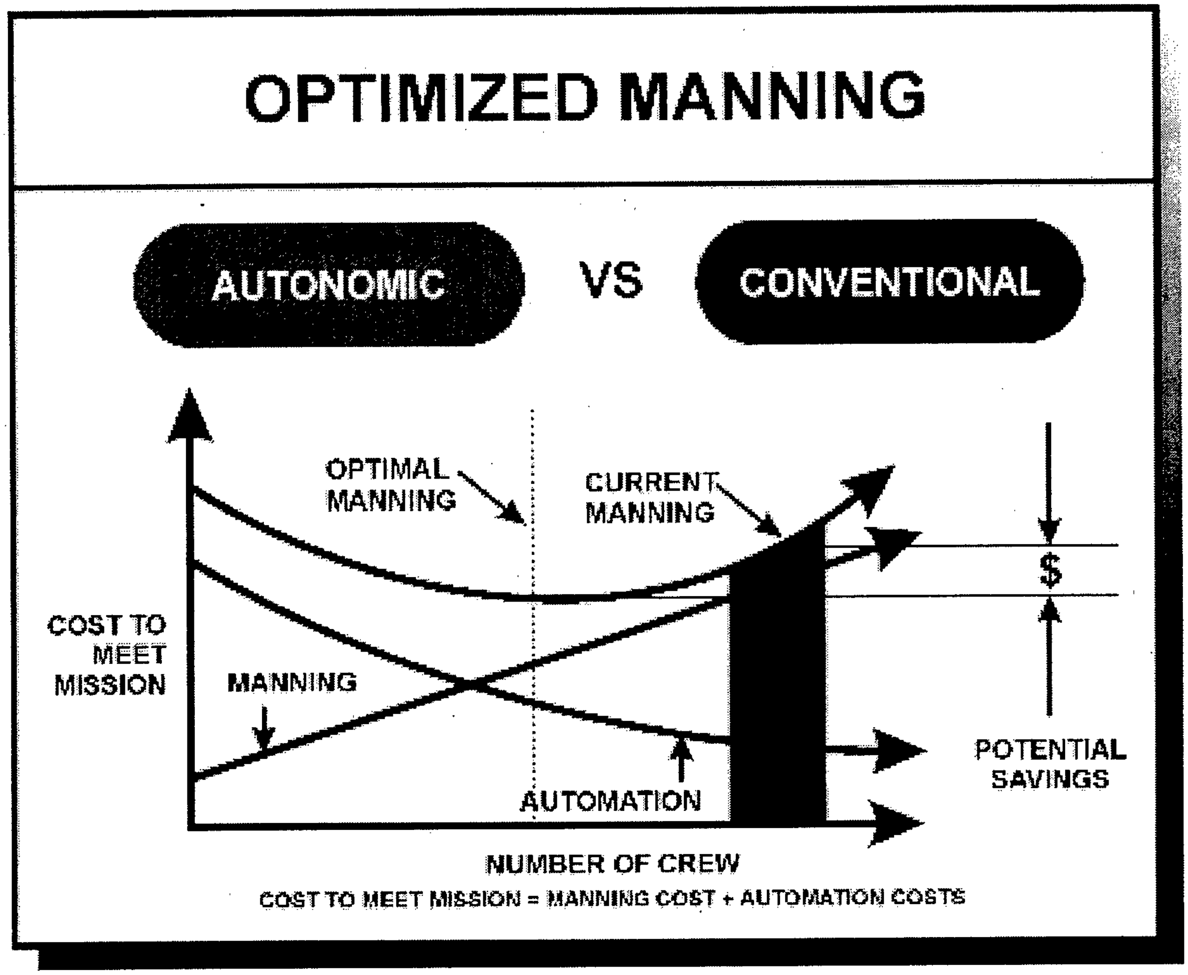


Figure 14 Manning and Automation Costs

10.3 United States Navy Perspective Capital Investment Analysis

In the context of the United States Navy, profit is not an underlying goal rather the ships are a "public good" of the nation and the net benefit is that the annual O&S budgets of the Navy will shrink. This money can either be reinvested in upgrading naval equipment or used as a reduction in the national defense budget.

A cost benefit spreadsheet is used to determine the economic benefits of installing the RSVP system on a US Navy DDG-51 class destroyer with three gas turbine generators, and four gas turbine powered main engines. The estimated cost of the RSVP

system health monitor components are presented in Table 12.

Cost Calculations		Cost per unit	Number of units	Cost
Human Computer Interface	Engineering Control Stations	$15,000.00	4	$60,000.00
System Health Monitor	Two SHM/machine	$2,000.00	14	$28,000.00
Intelligent Component H.M.	10 ICHM/SHM	$500.00	140	$70,000.00
	12 Sensors/ICHM	$10.00	1680	$16,800.00
	Software Basis	$50,000.00	1	$50,000.00
	Software Cost Per Unit	$5,000.00	7	$35,000.00
	Installation Cost Per Unit	$125,000.00	7	$875,000.00
			Total	$1,134,800.00
			Per Engine	$162,114.29

Table 12 Cost of the RSVP System Health Monitor Components

By allocating many of the crew tasks to the automated machinery monitoring system the crew could be reduced by 4 officers and 30 enlisted men. The personnel costs are a combination of direct costs such as pay and allowances and variable costs such as recruiting, training, and support infrastructure. A weighted average cost for officers is $107,000 per year and $63,000 for enlisted personnel (Naval Center for Cost Analysis, 1997). The net effect is a 23.62 Million-dollar annual manpower budget savings per ship.

The average annual DDG-51 direct maintenance costs per ship are shown in Table 13.

Reported Maintenance Labor Man-hours	$42,884.00
Repair Parts	$1,574,599.00
Afloat Maintenance Labor	$27,860.00
Total	$1,645,344

Table 13 Average Annual DDG-51 Direct Maintenance Costs

The sensors and the new approach of "conditioned based" maintenance is expected to reduce the annual maintenance costs by 25 % representing annual avoided costs of $3-4 Million dollars.

The economic analysis is on a Net Present Value (NPV) basis therefore a discount rate (DR), which will be used to discount future cash flows, must be chosen. The DR equals risk-free return plus a risk premium. The risk-free return historically has been based on safe US treasury bills and is currently about 6.5 %. The risk premium is a variable used by the investor to value the risk associated with various business ventures. The government discount rate is usually less than the corporate rate. The corporate rate more heavily discounts future cash flows making projects with short-term returns look more desirable, because they are more interested in short-term returns to maintain a healthy financial reputation and keep investors happy.

A discount rate of 10 % is used for the government as it accurately represents current Navy ship acquisition calculations and a discount rate of 18% is used to compare what a commercial shipping company might use for this project type. The conclusions are based on the Net Present Value of the project on a cost vs. benefits basis over a lifecycle of 25 years. Although this analysis is not trying to compare venture alternatives, it is trying to show that this proposal is economically feasible.

10.4 Results and Conclusions

The results from a government perspective (10% DR) show that from reduction of crew alone the investment has a payback period of 1.1 years, and results in net lifecycle cost savings of $19.52 Million dollars per ship. When maintenance savings are included the payback period is less than a year, and the lifecycle savings are $23.62 Million dollars per ship. When using the Commercial Discount Rate (18%) the payback periods are the same (as expected) but the overall lifecycle savings per ship are lowered to $14.38 Million dollars and $11.73 Million dollars when maintenance savings are excluded.

As with all capital investment decisions, there is an amount of uncertainty involved in the financial analysis, such as the actual number of crewmen removed. Perhaps the union or the company's employment policy will not allow the maximum reduction of crew. There are also legal requirements for specific crewmen such as US Coast Guard regulations requiring lookouts to be stationed on the bridge, and U.S. Navy requirements for damage control personnel. The goal of crew reduction should be to drive to the legal minimums and then revisit the basis for those legal limits. For example there is mature technology (as mentioned in Chapter 3), available that will allow automation of some of the damage control functions.

With respect to the maintenance savings, statistically predictions show that a condition based maintenance system, versus planned maintenance, will be less expensive but the predicted 25 percent savings may be higher or lower than the actual. Additional savings will be realized for new construction ships since the habitability spaces will be smaller for a smaller crew and the additional available space can be used for the ship's mission contributing to a less expensive more capable ship. The estimated risk of this technology is very low. The components that make up the automated machinery monitoring system are mature, commercially available, and have been demonstrated on test platforms. The results of this study suggest that insertion of the RSVP technology to reduce manpower and maintenance costs is a smart economic and operational decision, for both US Naval and Commercial vessels.

Chapter 11 Conclusions

This thesis presented a design methodology to properly implement candidate automation technology aboard US Navy ships. The methodology was applied to the RSVP Machinery HMS as a case study. The method for implementing the HMS calls for determining the information requirements so that the HMS captures and improves upon the operational knowledge and control of machinery by a smaller crew. Although every step of the information requirements determination method was at least investigated, they were not all exercised in great detail. A better test of the method could be performed by a colloberative team with the resources to visit more ships and conduct more interviews and scenario developments. The functional allocation process is very time demanding as well and would be better handled by a team.

The goal of developing a methodology for determining the sensors and information requirements to properly implement a machinery Health Monitoring System (HMS) aboard ship whose purpose is to provide situational awareness and control of the engineroom machinery was met. The technology survey, methodology, and interview results can be used as a starting point model of how implementation can be performed on other candidate machinery monitoring and control systems.

The demonstration of the Method on the RSVP Machinery Project as a case study was successful in determining what sensors are important, how often they should be updated and what types of smart operator aids are desirable in the various scenarios used. The methodology results could be improved by conducting more detailed interviews aboard ship, and by working directly with the engineers that write the Technical Manuals and Operating Procedures for the machinery being automated. General Conclusions

Several general conclusions and experiences appeared important to the author during the process of trying to implement a new automation system aboard a navy vessel. The following comments are noteworthy.

- The implementation method could be more efficient if there were more collaboration among small businesses and government labs because there are still "stovepipes" to be broken down to maximize the integration of all parties involved in the development of an automation system for shipboard use.

- Human engineering is not an exact science. To design and field an automation system, all engineering disciplines must be involved early and communicate frequently. Automation, if not properly conducted, actually leads to more work and more error. The designer must be made completely aware of the required context of use and capabilities of the system delivered to the fleet, otherwise it will become a "gray box" in the corner that is under utilized, if at all. Always inject user feedback into the design process early on.

- The commercial shipping industries and cruise lines have been highly automated for decades, and will continue to drive towards minimum manning to keep their operating costs in line. The Navy must look to the commercial industries and small businesses for a market survey of science and technology developments, since that sector and COTS products are advancing more rapidly than Department of Defense programs can. Military shipboard equipment designers have traditionally relied on the application of military specifications and standards to ensure survivability during a conflict. The result was long development cycles, unique military specified designs and high costs. To ensure that the equipment and systems deployed will continue to support the sailor while in a warfighting environment, the COTS selection process should select 2 to 3 of the most promising candidates and perform functional and pre-qualification tests on the candidates before finalizing the design. These tests could include Electro Magnetic Interference, temperature, humidity, shock and vibration performance in simulated shipboard environments [24].

- Cultural changes must take place in many areas. The smart ships will require "smart sailors" who have a working knowledge of PCs and IT systems. The Navy training pipeline must be able to adjust for the new technologies and the new sailors. The

Navy does need to move forward with automation, but must approach the implementation of promising innovation technology with caution, so that it is done right. The paradox is that if automation development is too rapid, the crew force structure and expertise will not match the technology advances aboard ship resulting in an ineffective platform.

- In some cases the drive to minimum crew size can go too far, even if unintentionally, since the design crew size is usually not the crew size that puts to sea. It is often smaller due to training ashore, illness, leave periods, recruiting and training school graduate shortfalls. If there is no margin, then a small crew could quickly become fatigued and readiness would suffer.

- The final observation is that insertion of the RSVP technology to reduce manning and maintenance costs is a smart economic and performance decision for both US Naval and Commercial vessels. But Be Cautious; It can be too much of a good thing!

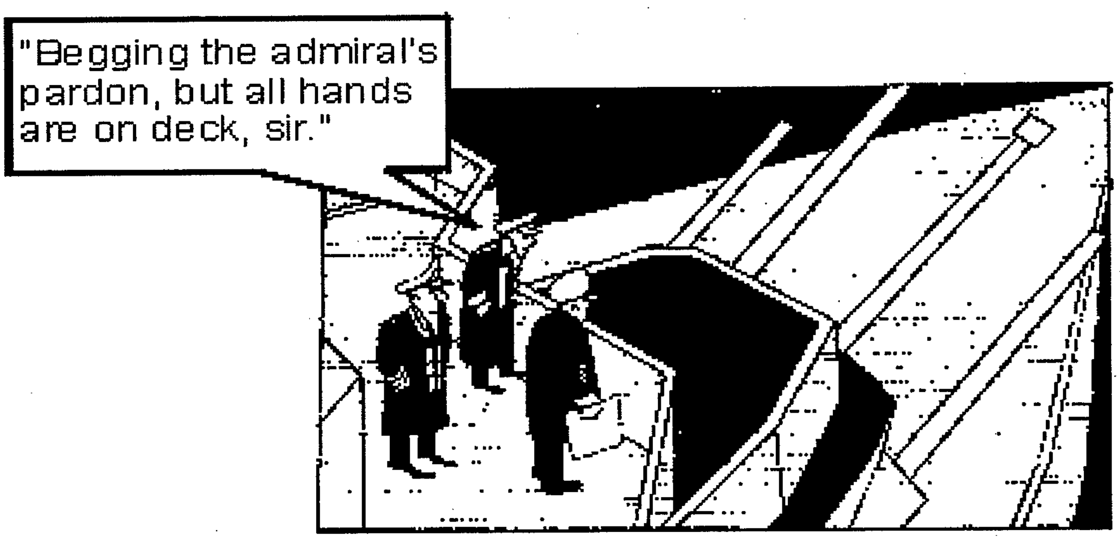


Figure 15 Can Manning Reduction Go Too Far

11.1 Recommendations for further Study

The RSVP ATD is progressing towards final design of the system architecture and human computer interface, and will be conducting land based testing this summer of 2000, followed by environmental testing on the Ex-USS Shadwell, and finally at sea trials aboard the USS Ticonderoga (CG-47). In all phases of this process, more interviews and observations should be conducted with the users and test engineers of the system. A cooperative design group should be formed to bring the system designers together with the shipboard procedure authors and the manufacturer's tech manual authors for the most applicable context of use and information requirements.

The RSVP ATD also must field the damage control, structural, and personnel monitoring and control automation systems aboard ship. A similar method for determining the information requirements and how to properly implement those systems should be pursued.

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Appendix A Site Visits for Research and Interviews

This Appendix presents the site visits and information gained in the research phase of this thesis. This information not only provides background and context for the thesis but also provides valuable opinion and insight into the overall problem of operational costs, manning reduction initiatives, automation and the interplay between the three.

Oceana Sensor Technologies Inc.

Oceana Sensor Technologies Inc. (OST)

1632 Corporate Landing Parkway

Virginia Beach, VA. 23454

Phone (757) 426-3678. Fax 757-426-3633

www.oceanasensor.com

OST is a small-business subsidiary of PCB Piezotronics Inc. of Depew, New York, and is located in Virginia Beach, Virginia. OST is a high-volume manufacturer of sensors for machinery monitoring and control and is helping to spearhead advances in smart and networkable sensors for use in machinery health monitoring, smart equipment, and industrial process control. OST was chosen by the RSVP ATD group to pursue development of the intelligent component health monitor which uses standard building blocks to integrate multiple sensing devices in smart modules for measuring characteristics such as Vibration, temperature, acoustic emission, pressure, corrosion, oil quality, and bearing load condition. The sensor signals can be processed at the local level or sent to higher HCI levels providing information about the state or health of specific

machine components.

The Information is then sent to a system health monitor via a digital network, which can use standard links such as Ethernet, or may be wireless as in the case of RSVP using emerging standards for radio frequency spectrum technology. SHM nodes are typically integrated with machine or process controllers and networked within a factory or warship automation system. These commercially developed products have seen application for bearings, gearboxes, motors pumps, compressors, HVAC, pulp and paper industry, power generation, machine tools, aircraft, construction machinery, and railway equipment. The US military is leveraging from these commercial applications for military application in smart network compatible sensors for Naval Surface ships, submarines, rotor craft, fixed wing aircraft, and armored and other ground support vehicles.

The size of the commercial market and vision for the future of the smart sensors is that original equipment manufacturers (OEM) of motors and gearboxes would develop products that contain onboard diagnostic capabilities using lightweight embedded piezoelectric vibration sensors. Manufacturers recognize that they can provide greater value in their products by producing their machinery with embedded sensors. This new breed of machine will assess the condition of its critical components and alert operators with intelligent decisions via programmable logic controllers. Critical machinery will be linked to the overall process controls and will trigger appropriate responses to any machinery conditions. Recently, improvements in design have provided low cost accelerometers that have enabled this market opportunity.

Fleet Maintenance Symposium

Valuable background and insight was gained by attending the fleet Maintenance Symposium 1999 whose focus was "optimizing readiness through technology". The symposium provided an opportunity to examine the many facets of fleet maintenance and

explore ways of improving effectiveness, quality and responsiveness to maintain readiness while reducing manning. This American Society of Naval Engineers event, also provided an opportunity to be exposed to the cutting-edge technologies and businesses that produce them.

The discussion of reliability centered maintenance (RCM) pointed out that 80 to 90 percent of equipment does not wear out, rather it has unpredicted failures, and thus 80 to 90 percent of equipment life would not be extended from PMS or overhaul. The goal is to reduce PMS to only that required for continued normal operation, based on the history of equipment performance. Maintenance reduction philosophies can be applied at the unit, intermediate, and depot level maintenance activities. CBM and RCM principles must be promoted and accepted through training because there is a cultural barrier. Both the surface and submarine maintenance programs (SURFMER, and SUBMEPP) have found no increase in CASREPS or safety problems on ships where the reduced maintenance principles were tested.

Another hurdle to overcome is the fact that actual repair time is much much less than administrative and preparatory work. Eliminating a 10-minute job could save several man-hours.

Admiral Martin Clark, CINC Atlantic, reiterated the need for equipment that will last without PMS and without inspections because reduced maintenance and longer mean time between failure (MTBF) is what the fleet needs. With a smaller number of units in the fleet and yet a still aggressive operating tempo, the problem is availability and how to minimize downtime of units for maintenance. He added words of caution that human engineering must be considered on the new system designs. Be aware that the sailor in a 95-man crew on DD-21 is going to have to be much more sophisticated than today's sailors. Training paradigms need to shift to keep pace with the fleet. There is no time to stop and retool, schools must adjust continually.

Large man-hours and maintenance savings can be realized from implementing

change aboard carriers since one-third of the Navy crewmen serve on carriers, and due to their sheer size and their 50-year lifecycle. Examples of initiatives are 70/30 copper nickel pipe, which reduces maintenance in later years, and new methods of hydro blasting for nonskid removal which don't require extensive cleanup afterwards. Automating the Tagout System on a carrier where 400,000 to 500,000 tags need be hung during maintenance periods, can be reduced to 25,000 by not hanging duplicate tags. More and better tank level indicators allow sailors to avoid entering tanks, which often damages coatings and costs man-hours.

Mr. Tom Connors of the Military Sealift Command (MSC) discussed goals for modern technology insertion, and minimum crew and how they could be applied to the U.S. Navy. A planned maintenance tool Ship Automated Maintenance (SAM), automatically records repair history and machinery history, and plans and interacts with the ships force work list, CASREPS, deck and engineering logs. This database is hooked up to the COSAL parts ordering system. Estimated savings are 4 Million dollars per year at a one time cost of $25,000 per ship. A lube oil analysis system database that sends data to a shore based laboratory provides rapid detailed results at a cost of $6000 per ship per year eliminating the need for crewmen to draw oil samples and mail them off to the lab (a slow process). The automated Vibration Monitoring System (VMS) uses data pickup points and a machine bar code where a hand-held reader can download the vibration analysis, analyze it onboard and electronically send a monthly report to the maintenance activity at a onetime cost of $35,000 per ship. The MSC estimates that implementing all three initiatives can save $50,000 per year per ship.

The US Coast Guard is also applying RCM principles to high impact applications. Positive aspects related to the success of the Coast Guard initiatives is that senior leadership supports innovation, matured technologies are becoming available, and newer cutters are being equipped with condition monitoring systems.

Other initiatives to reduce manning were discussed, such as preservations and coatings that last much longer than today's "paint, chip and repaint" methods. To reduce

cleaning man-hours, stainless steel heads and no wax decks can be installed.

Finally a comment regarding the USS Yorktown smartship initiative is that the cleaning and preservation of the engineroom looked exceptional and yet 75% of the enlisted men in engineering were selected for advancement due in part to the reduction of workload allowing more time for advancement exam studies. Be careful not to cut manning too much and too quickly, because there are improvements in the knowledge level and quality of life of the crewmen when man-hours are reduced.

Office of Naval Research

Office of Naval Research (ONR)

ONR 334

800 North Quincy Street

Arlington,VA. 22217-5660

Phone (703) 696-4719

At ONR, Mr. James E. Gagorik, program officer ONR 334, discussed the execution plan for the RSVP program and the remaining elements for success. In discussing this thesis plan and methodology, he stressed the need to assess the true context in which the system will be operated, and assess the operators needs and opinions with regard to implementation of the new system. Program execution guidance was valuable in understanding the process from concept to field-tested system.

NAVSSES Philadelphia Site Visit and Interviews

Naval Surface Warfare Center Carderock Division (NSWC-CD)

Ship Systems Engineering Station (SSES)

Philadelphia, PA. 19112-5083

code 93353, 9332, 9113.

Phone (215) 897-8081, 897-7806, 897-8492

Hoffmandj@nswccd.navy.mil, burnsje@nswccd.navy.mil

AEGIS Training and Readiness Center Detachment (ATRC)

Naval Business Center

Building 480 (NSWC-CD SSES)

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Phone (215) 897-8427, 897-7650, Fax (215) 897-8525

Salmonsdj@philly.atrc.navy.mil, millerwr@philly.atrc,navy.mil

Three visits to the Naval Surface Warfare Center Carderock Division, Ship Systems Engineering Station (at the former Philadelphia Naval shipyard) were conducted for research on the thesis.

The first visit was to attend a meeting with the machinery and electrical systems department to gather information on the reliability, newest modifications, and component failure history of the Allison 501 K-17 and 34 Gas Turbine Generators. The discussions involved Gas Turbine Generator controls including the local control panel (LOCOP) and its upgrade the fully automatic digital control (FADC) as well as ICAS interface connections and processing. The future FADC may have split screen display with half for sensors and controls the other half as an ICAS workstation. Instead of over hauling control cabinets aboard the DD-963 class the Navy is installing FADCs with the capability for CBM and compatibility with ICAS. Both control systems are based on the Woodward Governor with diagnostic and or prognostic software included. There is an initiative to incorporate these control systems into a CBM program to plan repairs, flag

needs, control equipment for smart plant lineups, and Casualty responses. The RSVP system can enable this link to provide troubleshooting and Diagnostics after any event. A review of the K-17 top management analysis and initiatives which lists component failures by most common to least, provides insight into which components are most critical to properly monitor and predict failure before it occurs. The Failure review board (PMS 400D) analyzes and catalogs the responses from all ships and enters this information into an automated failure analysis database.

The engineering groups interest in the RSVP systems, which enable CBM philosophy to be used on the gas turbine generators, is due to the removal of maintenance items, the improvement upon failure rates, the correction of common failure modes, and the diagnostic and or prognostic software that will prevent these failures.

The second visit was to the ATRC to join the CO and Engineer of the smartship and attend training on the technologies being installed as part of the smart ship initiatives. Systems demonstrated were the Integrated Bridge System for automatic navigation, voyage planning, digital nautical charts, and helm and throttle control, and the Engineering Control System Equipment providing flat screen displays and push button control of the main engines and gas turbine generators and associated auxiliaries.

During this visit the smartship CO and Engineer were interviewed on their opinions of the smart ship initiatives and how the RSVP system can best be implemented to address their concerns about and expectations of the next generation of smart systems. Another category of expert opinion was explored by interviewing the instructors that were conducting the training.

The third visit was also to the ATRC detachment and was made to attend classes with the Prospective Engineering Officers (PEOs) in training for assignment as DD-51 class Engineers, and to interview these PEOs as well as crewmen from the engineering department of the USS Roosevelt DDG-80. During this period the remaining categories of system expert were interviewed such as the In Service Engineers, senior and junior instructors, and senior and junior operators from the Roosevelt.

Appendix B Final Interview/ HMS Questionnaire

This Appendix presents the copy of the final version of the interview questionnaire used for this study.

Participant Consent Form

LCDR Brian P. Murphy, USN, is asking you to participate in a study of a shipboard machinery health monitoring system (HMS). The information from the study is part of a graduate thesis regarding how sensor information can be used to automate human tasks to reduce crew size. The thesis will be reviewed as a resource for the implementation of sensor/virtual presence technology in the Reduced Ship Crew through Virtual Presence Advanced Technology Demonstration (RSVP) (ATD). By participating in this study, you will help us understand what features are essential or may be useful and in the HMS design.

During the survey, you will be asked to answer a series of questions. These questions are designed to help us better understand the way gas turbine generators (GTG) are currently monitored and maintained and the information you require to monitor performance and diagnose problems. We will use the information that you provide, to improve the HMS user interface.

We will audiotape your interview so that later we can review the information you have provided. The tape is for our evaluation of the system, it will only be used by the HMS development team.

The data you generate during this study (written responses, verbal responses, audiotape), will be kept strictly confidential. The information you provide will have your name removed and only a number will identify you during analyses and any written reports of the research.

You may withdraw from this study at any time.

If you have any questions, please ask them now or at any time during the test.

If you agree with these terms, please indicate your acceptance by signing below.

Signature:____

Participant Demographic Form Regarding Gas Turbine Generator Experience

1. Rank/Civilian Job Level: ______________________________*e.g., Enlisted GSE*

2. Rate/Job title: ______________________________________*e.g., In service engineer*

3. Current Duty Station/Workplace: ________________________

4. Years of Experience: __________________________________

5. Training level/Jobs Held: ______________________________*e.g., EOOW, MPA*

6. Education Level/Degree(s) held: _________________________*e.g., BS in EE*

7. Systems you've seen/used: ______________________________*e.g.ICAS, ECSE, others*

8. Briefly describe any elements of your job that are related to the Allison 501 K17 or 34 Gas Turbine Generator Sets (GTGS): *e.g., Test & validate control system, operator, instructor.*

____

9 a. If you have experience with the Integrated Condition Assessment System (ICAS) software tool, please describe in days, months, or years used.

b. How comfortable do you feel using ICAS? Circle the number that most closely indicates your level of comfort.

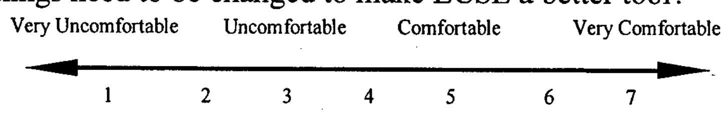
c. What things need to be changed to make ICAS a better tool?

Very Uncomfortable		Uncomfortable		Comfortable		Very Comfortable
1	2	3	4	5	6	7

10 a. If you have experience with the Engineering Control System Equipment upgrade (ECSE) by Litton Corp., please describe in days, months, or years used.

b. How comfortable do you feel using (ECSE)? Circle the number that most closely indicates your level of comfort.

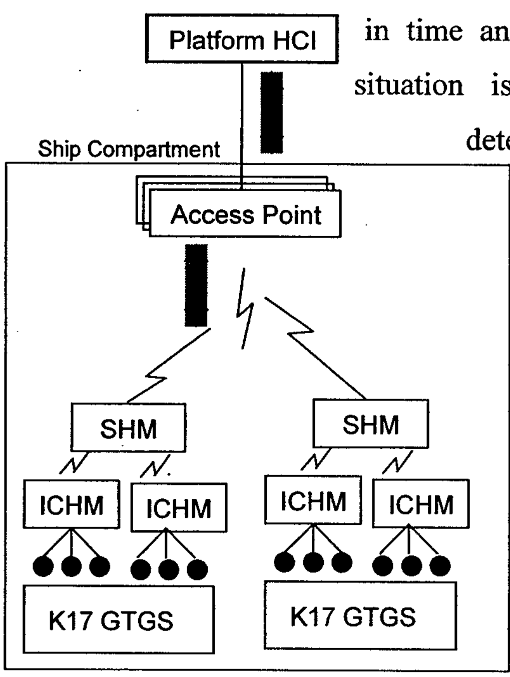
c. What things need to be changed to make ECSE a better tool?



Introduction to Machinery Health Monitoring System (HMS)

Automated machinery monitoring and health assessment will enable rapid determination of system configuration and operational status; early detection of system faults and adverse operating conditions; timely and efficient equipment restoration decisions; and logistic support coordination (scheduling repairs and ordering spare parts). This information, together with the status and shared knowledge of the watchteam gives situational awareness.

"Situational awareness" of a crew responsible for the monitoring and control of machinery encompasses the knowledge needed to remotely manage the operations of a machine at each point in time and to anticipate required actions in the near future. The situation is determined by combining sensor measurements to determine the status of a machine. A coherent and user friendly human-computer interface, where raw sensor data is transformed into knowledge and presented to the operator, is key to an effective situation assessment.



A conceptual overview, demonstrating a machinery health monitoring capability for an Allison 501K-17 GTGS, is shown in the adjacent figure. The abbreviations shown are: HCI – human computer

interface, SHM– system health monitor, and ICHM – intelligent component health monitor. The sensors (circles) monitor parameters such as temperature, pressure, vibration, lube oil flow and level. Sensor data is automatically logged and is available to operators on request. Alerts, warnings and alarms will be triggered from adverse readings and trends. The Health Monitoring System (HMS) can recommend action, display alternatives and the consequences of taking the action, or take automatic action and continue to display system status and configuration. The HMS will be designed for compatibility with the Integrated Condition Assessment System (ICAS) but is a much more powerful and higher level operator aid.

The proper design of this system requires an in-depth knowledge and understanding of the tasks that are to be supported and the environment and context in which those tasks are to be performed. The shipboard operator's experience and understanding of the environment in which the system is to be used, must be included in the early design stage. The questions that follow attempt to establish what information you need to safely and accurately perform your job responsibilities. Your answers will assist us in determining how sensor data will be analyzed and displayed, how much data should be logged, how much assistance and control the interface should provide, and what levels of information access should be provided for various tasks.

The questions solicit your opinions about several aspects of an HMS system under a hypothetical scenario. Answer the questions with this scenario in mind. There are no right or wrong answers to these questions. Instead, we are looking for your opinions about how the sensors and controls would best help you to determine the problem, realign the plant and take corrective action as rapidly as possible, all with confidence that you have determined the actual problem and taken the proper action. Please answer the questions as thoughtfully as you can.

Machinery Health Monitoring System Scenario

(Your watch progress from routine evolutions to abnormal conditions, and finally casualty conditions.)

You are coming on for your first watch of the mission; you are conducting a careful pre-watch review of all system's status. You check logs and update the status boards, and relieve the watch.

While remotely monitoring the SSGTGs from your central watchstation, you get a SSGTG warning light. You run through the possible causes in your mind and begin to trouble shoot the problem.

Several alarms come in while you are investigating. You have a combination of alarms that indicate the need to shut down a SSGTG. Your priority is to maintain electrical power for this mission critical period.

Think of the demands on you as you handle the casualty and the watch, and imagine what information and diagnostics would be useful as an operator aid to help you make the right determinations and take proper actions during your watch.

Machinery Health Monitoring System Questionnaire

Questionnaire Goal:

Determine User Information Requirements for monitoring and control of the Allison 501 K17/34 Gas Turbine Generator Sets (GTGS).

General:

a. Briefly describe things that make your watch routine pleasant and productive or unpleasant and unproductive. (example: time pressure can cause stress and mistakes)

b. If you could change five things that would make **starting** an SSGTG better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

c. If you could change five things that would make **operating** an SSGTG better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

d. If you could change five things that would make **securing** an SSGTG better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

e. If you could change five things that would make **operating during a casualty** better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

Monitoring:

a. What information is essential for you to operate safely during a Casualty? (E.g., Which sensor readings would you want to see?)

b. What information is essential for you to safely start an SSGTG?

c. What information is essential for you to safely **operate** an SSGTG?

d. What information is essential for you to safely **secure** an SSGTG?

e. If you only have three sensor readings, what 3 readings would you pick?

f. Are there any additional sensors you would want installed? (that are not currently available)

g. What conclusion would you make from say a low lube oil pressure alarm followed by a high bearing temperature warning?

h. What type of "intelligent" system support would be most valuable to help you with problem **diagnosis**? Rank their relative importance. (1 being the most important)

_________ The system tells you what the most likely problem is; you decide what actions to take.

_________ The system prompts each of your actions.

_________ The system displays the steps of the EOSS.

_________ The system takes action after your approval.

_________ The system takes action automatically, without your approval.

_________ Other: ____

i. What problem diagnosis are the hardest to figure out, and how could a "smart"

operator aid assist you?

What sensors are you *least likely* to trust for accuracy and why?

j. What "tricks" or ways to operate SSGTSs more efficiently than the manufacturer or manual prescribed, have you learned, that can be safely engineering into a new system?

Remote Sensor Processing:

a. What raw sensor readings should be displayed to the watchstander and how often should the readings be updated?

b. What information should an alert (warning) convey to help you accurately diagnose a problem?

c. What type of "intelligent" system support would be most valuable to you for **preventing** problems? Rank their relative importance. (1 being the most important)

_________ The system tells when a warning is expected to become an alarm

_________ The system predicts time to failure for a machine or component

_________ The system suggests ways to extend the life of a machine or component

_________ Other: ____

d. What type of historical sensor information is most valuable to you? (e.g. value temperature trends-e.g.: rising temp., etc).

e. For each item listed above in (d), how much history is desirable? (last 6 hr., last 24 hr, week.)

f. What presentation of information is most useful? (e.g.: graph of temperature, values of rates of change etc., logtaking format)

g. Should the information be open to all crewmen or is it necessary to restrict access to the data?

h. Is it necessary to restrict access to control functions?

i. If you answered yes to either (g) or (h), how would you accomplish restricted access?

j. Should the HMS display a machine's status automatically, or only when queried?

k. How many machines can you monitor simultaneously, without losing clarity of the situation?

1. Casualty Processing:

a. Regarding Data Indicators Processing, should the HMS determine what casualty that combinations of warnings and or alarms indicate? (1 being the most important)

_____ The system tells you what the most likely problem is; you decide what actions to take.

_____ The system prompts each of your actions.

_____ The system displays the steps of the EOSS.

_____ The system takes action after your approval.

_____ The system takes action automatically, without your approval.

_____ Other: ____

b. Regarding Determining the Casualty and Prioritizing Actions: What type of "intelligent" system support would be most valuable to help you with **combating the casualty**? Rank their relative importance. (1 being the most important)

_____ The system prioritizes the most critical problem to help maintain operations.

_____ The system lists impacts on the plant equipment.

_____ The system takes action after your approval.

_____ The system takes action automatically, without your approval.

_____ Other: ____

c. Regarding Determining first Response action: If "intelligent" checklists are available to help you with **navigating through the procedures** how would you **rank** their relative importance. (1 being the most important)

List them?

_____ The system identifies the procedural steps to be taken?

_____ The system lists an outline of the required steps?

_____ The system displays the actual procedure?

_____ The system tells you the correct order for your actions?

_____ The system keeps track of steps as they are completed?

_____ Other: ____

d. Regarding Fault Diagnosis and Supplementary Actions: Should the HMS display reminders of the most indicative sensors to determine recovery status and supplementary actions? How would you **rank** the relative importance of these aids? (1 being the most important)

_____ The system continues to display abnormal conditions.

_____ The system lists the required supplementary actions and keeps track as completed.

_____ The system displays the actual procedure.

_____ The system gives an outline of the correct order for your actions.

e. Regarding Directing Corrective Action: Should there be master and slave architecture for orders to be sent by a master console and carried out by slave consoles?

What should be monitored to assess when orders are complete?

f. Regarding Status of Casualty Display: Rank these display elements by their relative importance. (1 being the most important)

____ The screen shows General System status.

____ The screen shows Current System status.

____ The screen shows Current Priorities.

____ The screen shows Status of Actions.

g. In the future it will be possible to operate fully remotely. What degree of control should the HMS provide? Rank these features by relative importance. (1 being the most important)

_____ The Ability to Start and Stop machinery.

_____ To operate valves.

_____ To conduct plant lineups. (automate more valves)

_____ Other: ____

h. What control functions are most important to have?

i. Are there any functions that you would not want to be automated or remotely done and why?

k. What human function or daily requirement can be eliminated or routine procedure automated?

l. Should more remotely operated valves be installed?
Should most actions have a safety query? ("are you sure you want to stop Fuel Oil Pump #2?)

Maintenance:

a. Regarding Failure Predictions, Recommended Maintenance, and Material History:

How would you **rank** the relative importance of these aids? (1 being the most important)

_____ To display a prediction of remaining component life.

_____ To display recommended repairs.

_____ To automatically do a stock check for parts.

_____ To be linked to an Automated Parts List (APL) for ordering parts.

_____ Automatic Scheduling of Maintainance.

_____ To be linked to automatically maintain equipment history.

_____ Other: ____

_____ Other: ____

b. If you could move some of the maintenance functions off of the ship to the shore maintenance activities, What would you move off the ship? **Rank** the relative importance of the choices? (1 being the most important).

____

____

Appendix C Machinery HMS Questionnaire

This Appendix presents the complete questionnaire results. The responses to each question are summarized and in some cases ranked by most common response. They are presented in their entirety here for possible application to future implementation of automation systems.

General Watchstanding and Automation Interrelations

Factors That Make A Watch Routine Productive Or Unproductive

Question: Briefly describe things that make your watch routine pleasant and productive or unpleasant and unproductive. (example: time pressure can cause stress and mistakes)

The following comments about the points that make a watch progress poorly are summarized in the following sentences. The following sentences summarize comments received during the interview process. They are listed by most common response to least common response.

- Poor communications.
- Too many Evolutions overwhelm the watchteam.
- Steady state boredom leading to inattention.
- The addition of unscheduled tasks.
- Time pressure.
- Too many observers.
- Unforeseen problems occur
- Last-minute changes of plans.

- Lack of knowledge.
- Distracting Repairs and other Evolutions in progress.
- Poorly qualified operators make errors.
- Excessive noise.
- Lack of information.
- Extended time on watch.
- Fatigue.
- Monitoring system readings incorrect.
- An automatic shutdown without cause occurs.
- PACC and ECC consoles do not have any smart operator aids.
- Lube oil and Fuel Oil system problems at their interface.

Summary of comments about the points that make a watch progress efficiently are summarized in the following sentences. The following sentences summarize comments received during the interview process they are listed by most common response to least common response.

- Clear and concise communications.
- Well planned agenda with activities
- Properly qualified and trained operators.
- Teamwork.
- The full watchteam.
- Accurate reliable data on screens.
- Plenty of time for the assigned tasks.

- No misshaps or problems occur.
- When all hands read procedures together.
- Keeping the engineroom clean.
- Staying alert.
- When personnel report aboard already training.
- Reliable machinery.
- Watchstander interaction with equipment.
- Complete information available.
- Good time management.
- The ability to rove and maintain activities such as sampling, shift equipment and water wash of engines.
- The use of video of spaces and machinery.

Factors That Make starting an SSGTG Easier or More Productive

Question: If you could change five things that would make starting an SSGTG better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

The following sentences summarize comments received during the interview process they are listed by most common response to least common response.

- Provide an automatic sequencing system to start up the Generator automatically including verifying prestart requirements in prompting the operator when a prestart up is not met.
- Provide automatic paralleling of SSGTGs with the ability of operator to cancel parallel.
- Display the START time Analysis graph to predict machinery health.

- Provide automatic SSGTG startup for both standard and emergency startup conditions.
- Install individual Turbine inlet temperature (TIT) readings rather than the currently available average.
- Provide automatic paralleling and placing the standby GTG on the bus during a casualty.
- Provide all systems monitoring remotely for the main engines and generators and Auxiliary's.
- Remotely display more information such as all readings that are available at the local operating station.
- Provide Fuel manifold pressure remotely.
- Provide automatic one button push for configuration change from one Generator to the other.
- Provide remote tank level indication TLI displays.
- Provide ability to archive display parameters.
- Provided time stamp cannot weigh protective action occurs to be a will to determine the root cause. (May need milliseconds to split out events).
- Install more sensors and video cameras.
- Automate sufficiently to reduce watchstanders to 1one EOOW and one roving watch.
- Provide automatic chain of permission communications to start/stop a GTG.
- Provide automatic call station prompt of new plant configurations.
- Send electronic machinery health data to in Service Engineers for analysis.
- Provide alignment verification of supporting systems.
- Ensure maintenance logs are reviewable since last start or run period.
- Provide longer lead-time on alarms for earlier detection.
- Provide an automatic 30 second motoring of a GTG prior to start when a running GTG is in an alarm state, this speeds up getting the standby GTG online.

- Consider voice activated response systems

Factors That Make operating an SSGTG Easier or More Productive

Question: If you could change five things that would make **operating** an SSGTG better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

The following sentences summarize comments received during the interview process they are listed by most common response to least common response.

- Display all critical parameters graphically including pictures and improve data display at the EPCC.
- Redesign the audible alarms to weed out nuisance alarms and give a bell or buzzer to only the most critical parameters.
- Provide an auto paralleling system to maintain electrical power.
- Provide automatic oil sampling in assessment.
- Provide automatic fuel sampling and assessment.
- Give predictions recommendations and offer decisions for occurrences during the watch.
- Display the steps of the EOP and other guidance procedures and automate such that clicking on a step makes it happen.
- Similarly make automatic line drawings which have components that operate when clicked.
- Install more remotely operated valves.
- Provide more remote monitoring.
- Fix the turbine over speed protection system (TOPS) to prevent a loss of both GTG's causing a dark ship.
- Provide earlier warning systems and unmanned spaces to give more time to respond.

- Redesign the oil and Fuel systems to reduce leaks.
- Provide a means of online (running) water washing of GTGs.
- Ensure all readings available at the local console are also available on remote screens.
- Provide an automatic diagnostic and troubleshooting ability.
- Provide complete automatic logging and reviewing of machinery readings.
- Provide a time stamp on all events in sufficient detail to show what occurred first.
- Provide a bar graph of parameters that would change color from green to yellow to red, then flashing red as you approach alarm set points.

Factors That Make securing an SSGTG Easier or More Productive

Question: If you could change five things that would make **securing** an SSGTG better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

The following sentences summarize comments received during the interview process they are listed by most common response to least common response.

- Provide automatic shutdown checks and shutdown and cool down sequencing.
- Eliminate the manual observer for post Shutdown fire. (Use temperature sensors).
- Provide a one button plant mode logic change which provides automatic load shifting and load shedding.
- Provide an automatic permission and all station prompt before shutdown.
- Print out the shutdown parameters versus time and provide maintenance recommendations if necessary.
- Provided automatic 50 percent load reduction prior to securing for intermediate cool down. Provided automatic 60 seconds of motoring after rotation has stopped this keeps Fuel valves clean. Reduce the engine cool down requirement.
- Give a cautionary warning such as "this machine is carrying all load" to allow an

operator to change his mind about the shutdown order.

- Give notification "it is now safe for you to shutdown No. 3 GTG".
- Install more sensors and video cameras.
- Consider voice-activated communications and controls.
- Install a single plug and an Automatic Bus Transfer (ABT) for shore power needs, to speed up the process.

Factors That Make operating an SSGTG during a casualty Easier or More Productive

Question: If you could change five things that would make **operating during a casualty** better and more productive, what would they be? Don't limit yourself; assume you are "all powerful" and could change anything.

The following sentences summarize comments received during the interview process they are listed by most common response to least common response.

- Provided an auto recovery system, which prevents the loss of both GTG's thus maintaining power with automatic configuration changes.
- Provide smart operator aids, which define the casualty that has occurred.
- Provide smart operator aids that diagnose a casualty but choose carefully which scenarios are programmed.
- Provide a pop up window with recommendations and a picture of the problem.
- Provide more detailed screens with all parameters associated with a casualty.
- Provide automatic protective actions with user intervention.
- Provided time stamp list of problems and define the root cause.
- Provide the EOSS steps displayed and automatically checkoff as you complete them.
- Provide automatic casualty information reports to the OOD and CIC, which keeps from distracting the EOOW.

- Display parameters for both the problem GTG and the standby GTG.
- Provided a broader range of alarm set points and varying degrees of severity such as "shutdown possible", "probable", or "imminent". These can be based on the rise of > 100 degrees for possible shutdown, a rise of 200-300 degrees in TIT or TIT > 1900 degrees for probable shutdown, or TIT > 1975 degrees shutdown imminent providing an automatic cutback of 10 percent on fuel.
- Differentiate alarms that have come in due to a loss of power or have been cleared upon restoration of power. Currently there are too many alarms on a loss of power causing distraction.
- Provide a computer derived instant replay of events prior to casualty.
- Install cameras to view the spaces.
- Providing Halon activation on the EOOW Console.
- Provide space ventilation system controls at the EOOW console.

Monitoring

Information Essential For Operating SSGTGs Safely During A Casualty

Question: What information is essential for you to operate safely during a Casualty? (E.g., Which sensor readings would you want to see?)

The following list is for those sensors and design elements, which are considered essential during Casualties. They are listed from most important to least important.

1. Turbine inlet temperature, machine rpm, lube oil pressure.
2. Generator kW, voltage, and frequency.
3. Fuel Oil manifold pressure and lube oil temperatures.
4. Provide smart recommendations, keeping a Casualty window displayed.
5. Vibration sensors.
6. Provide predictions of machinery health and future performance
7. Provide filter pressures for the inlet, outlet, and differential pressure of the filter.

8. Fire alarm sensors.
9. Stator temperature.
10. The rest of these items were mentioned by at least one respondent.

- Provide trend analysis.
- Separate the quadrants on the screen.
- Provide liquid level indication.
- Provide Location of personnel.
- Provide: Coolant pressures.
- Provide percent power.
- Provide Fuel control valve position.
- Provide automatic ground detection and alert.
- Provide bearing temperatures.
- provide cooler inlet and outlet temperatures.
- Smoke detectors.
- Flooding alarms.
- Display the EOCC and EOSS procedures.

Information Essential To Safely Start An SSGTG

Question: What information is essential for you to safely start an SSGTG?

Following list is for those sensors and design elements, which are considered essential during SSGTG starting. They are listed from most important to least important.

1. The lube oil pressure.

2. GTG rpm, turbine inlet temperature, Fuel manifold pressure.

3. Prestart check off and alignment of systems in accordance with the EOP.

4. Vibration monitoring.

5. Voltage, current, starting air pressure, and in accordance with the technical manual.

6. The rest of these items were mentioned by at least one respondent.
   Lube oil temperature, module temperature, frequency, kW, Auxiliary's ready, fire extinguish is ready, tank and sump levels, coolant pressures, filter differential pressures, visual indications, control power supply indicators.

Information Essential To Safely Operate An SSGTG

Question: What information is essential for you to safely **operate** an SSGTG?

Following list is for those sensors and design elements, which are considered essential during SSGTG operations. They are listed from most important to least important.

1. Voltage.

2. Kilowatts.

3. Frequency.

4. Rpm.

5. Turbine inlet temperature.

6. Current.

7. Lube Oil pressure.

8. Vibration monitoring, fuel oil manifold pressure.
9. Give Predictions and alerts, give recommendations, and display the EOP and the EOCC procedures.
10. The rest of these items were mentioned by at least one respondent. Display Auxiliary's, bearing temperatures, load balancing in sync scope, trend analysis, troubleshooting, location of closest personnel, coolant pressures, all filter differential pressures, show system layouts, power level angle, sump levels, visual indications, listed loads, and provide auto load shedding.

Information Essential To Safely Secure An SSGTG

Question: What information is essential for you to safely **secure** an SSGTG?

The following list is for those sensors and design elements, which are considered essential during SSGTG securing. They are listed from most important to least important.

1. Turbine inlet temperature.

2. Rpm.

3. Analyze the Electrical buss loads to keep power continuity.

4. Provide the shutdown time sequence, provide automatic cool down sequence, and display the EOSS and the EOCC.

5. The rest of these items were mentioned by at least one respondent. Module temperature, overlay the shutdown time history graph, vibration monitoring, fuel manifold pressure, and visual indications.

What 3 SSGTG Sensors Are Most Important

Question: If you only have three sensor readings, what 3 readings would you pick?

They are listed from most important to least important.

1. Lube oil supply pressure.
2. Turbine inlet temperature.
3. Rpm.
4. kW.
5. Frequency.
6. Fuel manifold pressure.
7. The rest of these items were mentioned by at least one respondent. Current, voltage, vibrations, smoke detector, fire alarm, flooding alarm.

Additional Sensors Desired for Installation

Question: Are there any additional sensors you would want installed? (that are not currently available)

As the level of automation increases more sensors will be needed to satisfy the functions. They are listed from most important to least important.

1. Fuel Oil manifold pressure.

2. Individual turbine inlet temperatures.

3. New tank level indications for all equipment.

4. Starting air indications.

5. The rest of these items were mentioned by at least one respondent. Fuel control valve position, current fault relays, online oil sampling, filter differential pressures, sea water cooling systems, air flow, system diagrams, heat sensors, video cameras, Fuel Oil consumption, fire alarms, and flooding alarms.

Comment Regarding redundancy: for non critical parameters 1 sensor is plenty for critical parameters 2 sensors is desirable. Replaceable sensors is fine but would require as many as possible if sensors are embedded at the original equipment manufacturer.

Conclusions From a Low Lube Oil Pressure and High Bearing Temperature Alarms

Question: What conclusion would you make from say a low lube oil pressure alarm followed by a high bearing temperature warning?

The answers are summarized below in order of most common response to least common response.

1. A general lube oil system problem requiring correlation with other sensors to be sure of

cause.

2. A lube oil pump problem.

3. Loss of lube oil due to leaks in the system. In all cases the manuals would require a shutdown of that GTG.

4. A clogged lube oil filter.

5. Low sump level.

6. The rest of these items were mentioned by at least one respondent: Valve lineup problems, the monitoring software can sense rates of change that can be the key to determining the urgency of this pressure loss.

Ranking of Smart Diagnosis Operator Aids

Question: What type of "intelligent" system support would be most valuable to help you with problem **diagnosis**? Rank their relative importance. (1 being the most important)

The Following rankings are compiled from the 20 participant's rankings.

1. The system tells you what the most likely problem is; you decide what actions to take.

2. The system takes action after your approval.

3. The system displays the steps of the EOSS.
4. The system prompts each of your actions.

5. The system takes action automatically, without your approval.

Others mentioned:

- automatic action only for most serious casualties.

- System is linked to the IETM for troubleshooting.
- System is linked to the shore IMA for guidance.
- System gives recommendations with time to act, then an automatic shutdown Will occur if no actions taken.
- Battle override with push button actions.
- System must limit the number of recommendations to prevent confusing the operator.
- System shall have different settings for example peacetime steaming, wartime steaming etc. The system takes initial actions per the EOCC when a set point is reached provided that an operator warning is provided.

Hardest Types of Problems to Diagnose

Question: What problem diagnosis are the hardest to figure out, and how could a "smart" Operator aid assist you?

The answers for the hardest to figure out are summarized below in order of most common response to least common response.

1. Circuit cards, electronics and cable problems.
2. The non-classical problems which have no guidance in the troubleshooting manuals.
3. Vibration problems are hard to isolate from other sources.
4. Non-recurring or intermittent problems.
5. Startup problems occur and are very hard to recreate.
6. Electrical faults either shorts are grounds.
7. High turbine inlet temperature.

8. The rest of these items were mentioned by at least one respondent. Fuel system and Lube Oil system interfaces. Symptoms that disappear. Bearing temperature problems. Lube oil leaks. The shutdown that should not have happened.

Ideas on how a "smart" operator aid could assist you.

1. The smart troubleshooting guide determines the cause of the problem.

2. The time stamp order of occurrences gives the operator the ability to look back.

3. Cataloging shows trends to the period of interest. .

4. Try a scroll designed for circuit diagrams to make them more readable on computer screens.

5. Provide electronic tech manuals and troubleshooting guides.

6. Provide an alert when a 50 degree rise in Turbine inlet temperature occurs, give the operator Fuel pressure, Fuel control position, Generator load and load change.

7. Provide auto correlation; for example a high temperature alarm would require all associated temperatures, flows and differential pressures to also be checked.

8. Provide self-checking ground detection systems.

9. The start-up time chart overlay with historical starts would be very valuable.

10. Screen data should be updated based on operator's reaction and processing time

Sensors Least Likely to be Trusted

Question: What sensors are you *least likely* to trust for accuracy and why?

The answers are summarized below in order of most common response to least common response.

1. All tank level indications.

2. The analog or manual gauge, or a gauge that is out of calibration.

3. Fire alarms.

4. Bilge level alarms.

5. Flooding alarms.

6. The rest of these items were mentioned by at least one respondent

Shaft torque meters. Vibration monitors. Stator temperature RTDs.

Some comments to improve the sensors were offered.

1. Tank level indicators in a hostile environment performance decays very quickly especially Fuel Tanks at the oil/water interface.

2. To correct TLIs and bilge alarms build in time delays, which automatically adjust for various sea states.

3. Watchstanders must trust their indications.

4. All sensors must be operating within acceptable accuracy limits and have valid calibration.

5. Cameras can provide a Virtual Presence but still cannot "see" from all angles.

Design items that should be considered in the Navy's next generation of sensors and control systems for the SSGTG.

Question: What "tricks" or ways to operate SSGTGs more efficiently than the manufacturer or manual prescribed, have you learned, that can be safely engineering into a new system?

Design items that should be considered Navy next generation of sensors and control systems for the SSGTG.

1. Sailors Learn how to bypass the circuit or sensor to get the Generator started.

2. When procedures are poorly written they can be misinterpreted.

3. To rapidly remove load from a Generator, can put the outgoing Generator into manual mode and automatically pick up the load.

4. System lineup should be done by area or compartment, not by branch which passes through many areas and becomes time-consuming, and cumbersome.

5. Motoring the engine after shutdown keeps Fuel valves clean although not required by procedure.

6. The manual rapid start of the engine can be accomplished by manual operation of faulty morata valves.

Suggestions or comments with regard to these design items.

1. Manual revisions cost money, so that changes often do not get printed.

2. Manufactures are often reluctant to describe these tricks or bypass features.

3. Suggested tolerances are probably too tight; for example Paralleling window of opportunity is stated and then additional margins are added.

4. Online feedback capability to the manufacturer could provide permission to make manual changes aboard ship. Rather than the current feedback reports system.

Remote Sensor Processing

What Sensors are Most Important and How Often They Should be Updated

Question: What raw sensor readings should be displayed to the watchstander and how often should the readings be updated?

The choice of sensors is similar to those presented in the previous section. The answers are summarized below in order of most common response to least common response.

1. Lube oil pressure.

2. Turbine inlet temperature.

3. Engine rpm. And lube oil temperature.

4. Generator voltage and kW.

5. Generator Amperage, and Fuel manifold pressure.

6. Generator frequency, cooling pressures, and filter differential pressures.

7. Remote monitoring of the liquid levels and those Sensors required by the Operations Manual.

Second part of a question answers how fast the data should be updated. The responses from most common to least are as follows.

6. Near real time.

7. Data continuously displayed and updated.

8. Following data rates had equal number of votes: once per second, twice per second for most critical parameters, and four times per second.

9. The much faster update rate of 200 milliseconds or five times per second is better for time stamping data.

10. Ten times per second for time stamp data.

The following general comments about update rates were also mentioned.

4. When displayed meters are updated too frequently they flicker and distract the operator causing eye fatigue.

5. To correct flickering, design in dead bands to prevent hunting of the meter.

6. Decimal accuracy is not necessary; use standard gauge accuracy.

7. Updates in the milliseconds will unnecessarily burden the data storage and traffic architecture. Update on as requested basis only.

8. Use Summary groups and split the screen into quadrants for Data presentation.

Information A Properly Designed Alert (Warning) Should Convey

Question: What information should an alert (warning) convey to help you accurately diagnose a problem?

The following answers are presented from most common to least common response.

1. Alert should give a clear concise description of the exact component and its problem and should tell the set point and current reading
2. Give an accurate parameter reading with exact reading displayed and updated.
3. System should give a history of the alarm parameter and give correlations to other related parameters.
4. Console should recommend possible actions along with the alarm.
5. The system should give symptoms of various problems related to the alarm.
6. The remaining responses received at least one mention. Display the value that is at the set point. Eliminate Summary Alarms. Provide the scrolling display with time stamp on Alarms. Show the parameter's rate of change and give time to failure. Avoid too many warnings, which may confuse the operator. Give warnings when alarm is faulty. Current Navy practice for alerts in Alarms is adequate.

The Most Valuable"Intelligent" System Support For Preventing Problems

Question: What type of "intelligent" system support would be most valuable to you for **preventing** problems? Rank their relative importance. (1 being the most important)

The following ranking of operator aids is based on summary of the participant's rankings.

1. The system predicts time to failure for a machine or component

2. The system tells when a warning is expected to become an alarm

3. The system suggests ways to extend the life of a machine or component

Other: linked automatically with the IETM and display the information. Maintain a watch history log of events.

Most Valuable Type Of Historical Sensor Information

Question: What type of historical sensor information is most valuable to you? (e.g. value temperature trends-e.g.: rising temp., etc)

The following responses are presented by most common to least common.

1. Graphical display of parameters versus-time especially for GTG startup profiles.

2. Trend analysis especially for critical parameters.

3. Display parameters like paper logs do.

4. Provide trends only when asked for.

5. Display Fuel Oil and lube oil pressures expected at various loads.

6. The rest of these answers received at least one response.

Display rates of change. Display temperatures, vibrations and filter differential pressures. Display Fuel consumption and oil consumption. Display fire and flooding sensors.

Comments: trend analysis of sump levels can reveal system leaks.

Predictions and Prognostics are not necessary.

How Much History Is Desirable

Question: For each item listed above, how much history is desirable? (Last 6 hr., last 24 hr, and week.)

The following responses are listed from most common to least.

1. At least 24 hours worth.

2. Provide the ability to go back farther in time and decide.

3. A weeks worth.

4. Up to 48 hours worth.

5. Provide 30 days worth of logs available.

6. Have all data since last sensor or system maintenance.

7. The remaining answers all had at least one response. The amount of history is component dependant. There should be 15 minutes worth displayed on screen, and keep 20 to 30 minutes in an active buffer. There should be continuous daily downloading to an archive system. Data should be stored by the megabyte, and downloaded when buffer is full. Maintain a real-time display only, no logging requirements. Maintain up to four hours worth. Maintain as much as system can handle. Burn CDs periodically to download the data buffer.

Most Useful Presentation Of Information

Question: What presentation of information is most useful? (e.g.: graph of temperature, values of rates of change etc., logtaking format)

The following responses are presented by most common to least common.

1. Graphical presentation.

2. Display numerical values with the option to graph over an operator specified interval.

3. Display in log-taking format.

4. Display charts versus time.

5. Display bar graph trend analysis.

6. Provide pictures of spaces and components.

7. Display rates of change.

8. Display the data with alarm trip points.

9. Provide audible presentation along with the visual data.

Restricting Access To The Data And Control Functions

Question: Should the information be open to all crewmen or is it necessary to restrict access to the data?

80 percent of respondents said yes to open access for all. 20 percent favored restricting the information with the following comments. Restrict access to only engineering department personnel and supervisors. Present the information with differing levels of detail for example the CO the CHENG the EOOW and the EO. Restrict the ability to change information.

Question: Is it necessary to restrict access to control functions?

65 percent of respondents said yes while 35 percent said no.

Question: If you answered yes to either, how would you accomplish restricted access?

The following access restriction methods are presented from most common to least common response.

1. These two methods tied for first they are: A login and password system and Using the qualification system to control access at the watchstander level.

2. Plastic covers to give some forethought to operator's actions.

3. Strict access by minimizing the number of control stations.

4. Remaining items had at least one response each.

   Use magnetic zip cards.

   Provide over ride capability if a watchstander is not responding correctly.

   Provide layers of control depending upon importance of the component.

   Use fingerprint recognition.

Machine's Status Display Automatically Or Only When Queried

Question: Should the HMS display a machine's status automatically, or only when queried?

80 percent of respondents chose automatic while 20 percent wanted status displayed only when queried. Following comments are presented from most common to least common.

1. There should be an automatic display of the main engines and the gas turbine generators. Use as many details as possible while managing the screen real estate.

2. Non-vitals and Auxiliary's should only show system status when queried.

3. Machine status should only be displayed when queried.

4. The automatic displays should depend on how much screen room is available.

5. USS Yorktown used three screens to display the machinery's status.

6. Not in favor of pop-up screens because they could cover-up important parameters.

Number Of Machines That Can Be Monitored Simultaneously, Without Losing Clarity

Question: How many machines can you monitor simultaneously, without losing clarity of the situation?

The following answers are presented from most common to least common response.

1. The main engines and gas turbine generators- approximately five machines.

2. Current control screen shows too much. It should be four machines maximum.

3. It depends on the Systems State. Four to five machines can be monitored safely however in steady state more than 6 could be handled.

4. These times were each mentioned once: 7 to 10 machines can be monitored simultaneously. Three machines can be monitored simultaneously, or ten to 12 machines can be monitored simultaneously.

Casualty Processing

Ranking of Casualty Prediction Smart Operator Aids

Question: Regarding Data Indicators Processing, should the HMS determine what casualty that combinations of warnings and or alarms indicate? (1 being the most important)
The following operator aids are ranked based on participant's responses.

1. The system tells you what the most likely problem is; you decide what actions to take.

2. The system takes action after your approval.

3. The system prompts each of your actions.

4. The system displays the steps of the EOSS.

5. The system takes action automatically, without your approval.

Ranking of Smart Operator Aids for Combating a Casualty

Question: Regarding Determining the Casualty and Prioritizing Actions: What type of

"intelligent" system support would be most valuable to help you with **combating the casualty**? Rank their relative importance. (1 being the most important)

The following operator aids are ranked based on participant's responses.

5. The system prioritizes the most critical problem to help maintain operations.

6. The system takes action after your approval.

7. The system lists impacts on the plant equipment.

8. The system takes action automatically, without your approval.

Other: The operator is in control now and does not need smart aids.

Ranking Of Smart Operator Aids For Navigating Through The Procedures

Question: Regarding Determining first Response action: If "intelligent" checklists are available to help you with **navigating through the procedures** how would you **rank** their relative importance. (1 being the most important)

The following operator aids are ranked based on participant's responses.

5. The system identifies the procedural steps to be taken.
6. The system lists an outline of the required steps. The system tells you the correct order for your actions.
7. The system displays the actual procedure.
8. The system keeps track of steps as they are completed.

Other: The system warns of missed steps. The system lists equipment needed to do repairs.

Ranking Of Smart Operator Aids For Supplementary Actions

Question: Regarding Fault Diagnosis and Supplementary Actions: Should the HMS display reminders of the most indicative sensors to determine recovery status and supplementary actions? How would you **rank** the relative importance of these aids? (1 being the most important)

The following operator aids are ranked based on participant's responses.

1. The system lists the required supplementary actions and keeps track as completed.
2. The system continues to display abnormal conditions.
3. The system gives an outline of the correct order for your actions.
4. The system displays the actual procedure.

Master And Slave Control System Architecture And Carrying Out Orders

Question: Regarding Directing Corrective Action: Should there be master and slave architecture for orders to be sent by a master console and carried out by slave consoles?

70 percent of respondents said there was no need for master slave console architecture, while 30 percent said yes with comments. Comments: the console closest to the engine should have priority. Control consoles should only be placed in legitimate control areas. The EOOW and bridge consoles should have override capability.

Question: What should be monitored to assess when orders are complete?

The number one response for verification was to use console data and ensure that all remote consoles display the same information in the same way. Standard shipboard reports and communication will also provide verification.

Ranking of Smart Screen Displays for Casualty Status

Question: Regarding Status of Casualty Display: Rank these display elements by their relative importance. (1 being the most important)

The following operator aids are ranked based on participant's responses.

5. The screen shows Current Fault conditions.

6. The screen shows Current Priorities.

7. The screen shows Status of Actions.

8. The screen shows General System status.

Other: console configurations should be standardized so the display will always be familiar to all watchstanders. Therefore there will be no confusion in the heat of battle.

Degree of Control That a Machinery HMS Provides

Question: In the future it will be possible to operate fully remotely. What degree of control should the HMS provide? Rank these features by relative importance. (1 being the most important)

The following operator aids are ranked based on participant's responses.

1. The Ability to Start and Stop machinery.

2. To operate valves.

3. To conduct plant lineups. (Automate more valves)

Other: fully automatic operation with single button plant mode and load changes of the main engines and GTG's will require a significant addition of remotely operated valves.

Control Functions That Are Most Important To Have

Question: What control functions are most important to have?

Following responses are presented from most common to the least common response.

1. The starting and stopping of machinery.
2. Electrical power control and Electric Plant configuration changes.
3. Valve operations.
4. Valve lineup operations.
5. Safety critical items.
6. Manual operation backups for all functions.

Functions That You Would Not Want To Be Automated

Question: Are there any functions that you would not want to be automated or remotely done and why?

65 percent of respondents said there is no functions that they would not want automated. While 35 percent said yes with the following comments in order of most common to least common response.

Engine shutdowns should not be automatic but always by operator's choice.

No automatic function should cause a loss of electrical power to both sides of the ship.

Any overboard discharge or environmental concern should not be automated.

Motoring of the GTG's is already an abnormal situation and should not be automated.

All automatic functions must have the ability for operator intervention.

Function Or Daily Requirement That Can Be Eliminated Or Automated

Question: What human function or daily requirement can be eliminated or routine procedure automated?

The following answers are presented from most common to least common response.

5. No more paper logs taking.
6. No more oil sampling.
7. Delete sump and tank checks.
8. Routine PMS.
9. ICAS does have a download appliance or automatic logging as an interim measure.

Question: Should more remotely operated valves be installed?

All participants said yes but are cautious in selecting the most reliable remotely operated valves.

Should Most Actions Have A Safety Query

Question: Should most actions have a safety query? ("Are you sure you want to stop Fuel Oil Pump #2?)

60 percent of the participants responded yes, while 40 percent responded no with the following comments. Use interlocks to provide safety measures. The safety query depends on the importance of the machine. Only the most critical components should have the safety query.

Maintenance

Ranking of Smart Maintenance Operator Aids

Question: Regarding Failure Predictions, Recommended Maintenance, and Material History:

How would you **rank** the relative importance of these aids? (1 being the most important)

7. To display recommended repairs.

8. To display a prediction of remaining component life.

9. To automatically do a stock check for parts.

10. To be linked to an Automated Parts List (APL) for ordering parts.

11. Automatic Scheduling of Maintenance.

12. To be linked to automatically maintain equipment history.

Other: system should provide a daily burst of information via an Internet and satellites to the IMA or other ships for information and recommendations.

Maintenance Functions that Should Be Moved Off Of The Ship To The Shore

Question: If you could move some of the maintenance functions off of the ship to the shore maintenance activities, What would you move off the ship? **Rank** the relative importance of the choices? (1 being the most important)

The following answers are presented from most common to least common response.

7. As much maintenance as possible to be moved ashore with the exception of on watch equipment PMS to maintain the machine's health.
8. Maintain emergency repair maintenance on board.

9. Remove or eliminate routine PMS.
10. Remove or eliminate routine repairs or have a quick change out parts system on board.
11. Move internal inspections ashore.
12. Remaining comments were those mentioned once:

    Move scheduling of maintenance ashore.

    Move parts ordering ashore.

    Move shipboard cleaning ashore.

    Move calibration of gauges ashore.

    Move record keeping on machinery ashore.